

UNIVERSITY OF ALBERTA LIBRARY



0 0001 7251 612

DEPARTMENT OF THE INTERIOR, CANADA

HON. CHARLES STEWART, Minister; W. W. CORY, C.M.G., Deputy Minister

DOMINION WATER POWER AND RECLAMATION SERVICE

J. T. JOHNSTON, C.E., Director

IRRIGATION SERIES

BULLETIN No. 7

UNIVERSITY OF ALBERTA  
SEP 18 1935  
GOVERNMENT  
PUBLICATIONS

IRRIGATION PRACTICE

AND

WATER REQUIREMENTS FOR CROPS

IN

ALBERTA

(Revised Edition of Bulletin No. 6)

OTTAWA

F. A. AGLAND

PRINTER TO THE KING'S MOST EXCELLENT MAJESTY

1930

S  
613  
S67  
1930

SCI

EX LIBRIS  
UNIVERSITATIS  
ALBERTAE



**DEPARTMENT OF THE INTERIOR, CANADA**  
HON. CHARLES STEWART, MINISTER — W. W. CORY, C.M.O., DEPUTY MINISTER

**DOMINION WATER POWER AND RECLAMATION SERVICE**  
J. T. JOHNSON, DIRECTOR

---

**IRRIGATION SERIES**  
Bulletin No. 7

# **IRRIGATION PRACTICE AND WATER REQUIREMENTS FOR CROPS IN ALBERTA**

(Revised Edition of Bulletin No. 4)

**PREPARED UNDER THE SUPERVISION OF**

**J. S. TEMPEST**

*Commissioner of Irrigation*

**BY**

**W. H. SNELSON, A.M.E.I.C.**

*Senior Irrigation Specialist*

---

OTTAWA  
F. A. AGLAND  
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY  
1926

## FOREWORD TO REVISED EDITION

This bulletin is a summary of the results of ten successive years of experimental work undertaken to determine the "duty of water," i.e., the quantity of water (irrigation plus rainfall) required to produce good crop yields in dry districts.

There is also included some practical advice to beginners in irrigation regarding the preparation of the land and the most approved methods of applying water.

The purpose of the bulletin is to assist irrigators by making readily available for their use the conclusions reached as the result of careful and continuous experiments, in the hope that costly errors and wasted effort may thus be avoided.

J. T. JOHNSTON,

*Director, Dominion Water Power & Reclamation Service.*

OTTAWA, February, 1923.

# TABLE OF CONTENTS

## SECTION 1

	PAGE
Practical Information for Beginners in Irrigation.....	7
Levelling the Land.....	7
Laying out the Farm Laterals.....	10
Use of the Level.....	10
Proper Gradient for Farm Laterals.....	11
Proper Spacing of Ditches and Reasonable Threshold.....	11
The Different Systems of Irrigation and their Application to Alberta Conditions.....	11
The Free Flooding Method by Contour Ditches.....	11
The Border Ditch System.....	14
The Border Dyke System.....	16
The Furrow or Corrugation Method.....	17
Construction of Farm Laterals.....	18
Applying the Irrigations.....	21
The Use of the Canvas Dam.....	21
Points to be noted in Irrigation.....	22
Applying the Correct Depth.....	23
Night Runs.....	24

## SECTION 2

Irrigation Investigations.....	25
Outline of Work.....	25
Duty of Water.....	26
Physical Properties of the Soil and Subsoil.....	26
Fertility.....	27
Size of Irrigation Head and Depth Applied per Irrigation.....	27
Preparation of the Land.....	29
Seasonal Water Requirements and Time of Irrigation.....	29
Water used to grow the Crop.....	29
Transpiration.....	29
Percolation.....	29
Evaporation.....	29
Optimum Moisture Content.....	30
Diagram No. 1.....	31
Planning and Irrigation Schedule for the Farm.....	32
Duty of Water Investigations at the Brooks Experiment Station.....	34
General Cultural Methods Employed.....	34
Rotations.....	35
Schedule for Rotations.....	35
Water Requirements of Wheat.....	35
Diagram No. 2.....	36
Total Depth Received.....	37
Total Depth Used.....	37
Influence of Fertility.....	37
Time of Irrigation.....	37
Summary.....	39
Water Requirements of Oats.....	39
Total Depth Received.....	39
Total Depth Used.....	39
Influence of Fertility.....	39
Time of Irrigation.....	39
Diagram No. 3.....	40
Summary.....	41
Water Requirements of Barley.....	41
Total Depth Received.....	41
Total Depth Used.....	41
Influence of Fertility.....	41
Time of Irrigation.....	41
Diagram No. 4.....	42
Summary.....	42

	PAGE
Water Requirements of Flax.....	43
Water Requirements of Corn.....	43
Diagram No. 5.....	44
Water Requirements of Potatoes.....	46
Water Requirements of Peas.....	46
Diagram No. 6.....	47
Water Requirements of Mixed Grass.....	49
Water Requirements of Green Alfalfa.....	49
Influence of Age of Plant.....	49
Total Depth Received.....	49
Total Depth Used.....	49
Water Requirements of Sugar Beets.....	49
Diagram No. 7.....	50
Diagram No. 8.....	51
Total Depth Received.....	52
Total Depth Used.....	52
Influence of Fertility.....	52
Time of Irrigation.....	52
Water Requirements of Alfalfa for Seed (with Diagram).....	52
Summary of Investigations at Brooks Station.....	54
Duty of Water Investigations at Rosalene, Alberta.....	54
Water Requirements—	
Canada Blue Peas.....	55
Marquis Wheat.....	55
Abundance Oats.....	55
Bark's Barley.....	55
Green Alfalfa.....	55
Gold Coin Potatoes.....	55
Summary.....	55
Diagram showing Water Requirements of Crops at Rosalene Experiment Station...	56
Duty of Water Investigations at Coaldale, 1913-21.....	57
Summaries—	
Coaldale.....	63
Rosalene.....	64
Brooks.....	64

## SECTION 3

Water Holding Capacity of Soils.....	65
Water in the Soil.....	65
Hygroscopic Water.....	65
Capillary Water.....	65
Gravitational Water.....	66
Knowledge of Water-holding Capacity Important.....	66

## SECTION 4

Development of Sugar Beet Root Systems.....	70
Function of Root System.....	70
Requirements for Growth.....	71
Conditions affecting Supply of Growth Constituents.....	71
Food Supply.....	71
Air Supply.....	71
Moisture Supply.....	71
Optimum Water Content.....	72
Amount of Water used to Grow the Beet Crop.....	72
Seasonal Development of Sugar Beet Root Systems. Field Studies, 1927.....	72
Influence of Soil Fertility and Texture on Root Development.....	72
Influence of Soil Aeration on Root Development.....	74
Influence of Alkali Soil on Root Development.....	76
Normal Development in a Clay Loam Soil.....	78
Normal Development in a Sandy Loam Soil.....	80
Extension in Depth of Root Occupied Zone.....	80
Discussion of Yields.....	83
Relation of Root Development to Depth required per Irrigation.....	83
Conclusions.....	84

# ILLUSTRATIONS

	PAGE
Franna Scraper.....	7
California Model Buck Scraper.....	8
Farmer's Float.....	9
Fine Flooding from Contour Ditches.....	12
The Border Ditch System.....	13
Use of Ridger for making Borders.....	14
The Border Dyke System.....	15
Large Machine Ridger.....	16
Home-made Corrugator.....	17
"V" Ditcher in Operation.....	18
Machine Ditcher.....	19
Martin Ditcher.....	19
Large Ditching Plow.....	20
Diverting Water with a Canvas Dam.....	21
Use of Canvas Dam.....	22
Making Ditches at Brooks Experimental Station.....	28
"V" Notch Measuring Weir.....	23
Two Way Flow.....	24
Marquis Wheat.....	26
Princeton Blue Peas, Dry and Irrigated.....	46
Green Alfalfa (grown for Seed).....	48
Laying out Small Plots for Alfalfa Seed Tests.....	53
Sugar Beets following Alfalfa.....	54
Plate 1. Influence of Soil Fertility on Root Development.....	78
Plate 2. Beets in Wet, Heavy Clay Soil.....	75
Plate 3. Beets in Wet Soil Highly Alkaline.....	77
Plate 4. Beets on Well Drained Clay Loam Soil of Fair Fertility.....	79
Plate 5. Beets on Sandy Loam Soil with Gumbo Layer at 4½ feet.....	82

## MAP

Plan of Brooks Irrigation Experiment Station.....	at end of report
---	------------------



# Irrigation Practice and Water Requirements for Crops in Alberta

## SECTION 1

### PRACTICAL INFORMATION FOR BEGINNERS IN IRRIGATION

*Levelling the Land.*—The first, and probably the most important work which confronts the farmer who is preparing to irrigate his fields, is levelling the land. Too much emphasis cannot be placed on the necessity of having the fields properly graded and levelled before laying out the irrigation laterals. Properly levelled lands aid in the economical and uniform application of water, lessen the danger from over- or under-irrigation of any portion of the field, and enhance the prospect of good yields.

Much of the discouragement met with in a newly irrigated district is caused by poor crop yields from fields which, on account of their roughness, could not be uniformly covered with water. In many of the older districts large expenditures per acre have been made in levelling knolls, filling up depressions, and giving the field a uniformly graded surface. A farmer will never regret money spent on work of this nature.

The first and most important operation in levelling the land is done with the Fresno scraper. With it, all prominent and non-irrigable knolls are cut off and deposited in adjacent depressions. As this implement is familiar to all, no description of it will be given here.

Other implements used in levelling land are the "Buck scraper" and the "Float"—one model of the former and one of the latter being shown in accompanying illustrations.



Fresno Scraper

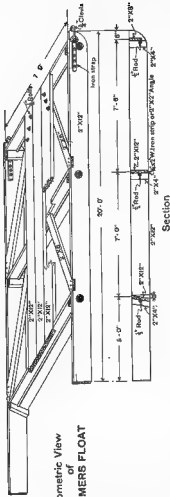
The California model buck scraper is made in widths varying from ten to twenty feet, and requires from six to twelve horses. This scraper operates on much the same principle as the Fresno, except that it is much wider and will do the work more rapidly. The cut, however, is not so deep. The long handle behind enables the operator to accurately gauge the depth of cutting when removing the earth from a knoll and to spread the load evenly when dumping.



The California Model Buck Scraper

The float is used after the heavier grading work has been completed with the scraper and after the land has been ploughed to smooth the surface. Floating must be done when the soil is rather dry as it cannot be done well when the soil is wet. A good float will both pulverize and pack the soil and is an indispensable implement on any irrigated farm. It should be made along the lines shown in the accompanying plan. The side members or runners should be made of two-inch by twelve-inch planks, twenty feet long. The centre and rear cross-pieces should be made from two-inch by twelve-inch planks. The front cross-piece should be made from a two-inch by eight-inch plank which, when in place, should be flush with the tops of the side runners, leaving a space of four inches underneath its bottom edge to permit of the passage of clods and rubbish. The centre piece should stand perpendicular to the ground and be placed eight feet behind the front cross-piece. The rear cross-piece should be placed seven feet behind the centre one and about five feet from the ends of the side members, and should have a slant of about fifteen degrees from the perpendicular. The bottom of the centre cross-piece should be shod with iron, to form a cutting edge for shaving off small knolls. Half-inch iron rods should be placed through the float behind each cross-piece and drawn tight with bolts and washers. The float should be braced laterally across the top with pieces of two- by four-inch timber. Bolt lugs for attaching a pulling chain should be provided on each side of the float near the front. It should be borne in mind that it is the centre cross-piece which does most of the work, as in a carpenter's plane. In all cases well-seasoned wood, free from knots or cracks, should be used. The front cross-piece acts merely as a brace; the back one as a general "smoother out" of lumps.

Isometric View  
of  
FARMERS FLOAT



It is important that the side members extend at least five feet behind the back cross-piece. The value of this arrangement will become apparent when the first ditch or hole is crossed. The back cross piece will be carrying some dirt which it will let down into the hole the extension runners meanwhile preventing the cross-piece from following the dirt down as it would tend to do if the runners did not extend beyond the rear cross-piece.

Fields should be floated both ways. Good floating ensures even depth of planting and a fine seed bed. A float of the above length and six to seven feet wide is a good load for four horses.

A Fordson tractor will pull a seven foot wide float, weighted with two to three hundred pounds of earth in sacks. If land is very loose the tractor will need extension ribs on the wheels.

*Laying out the Farm Laterals.* Considerable areas of the irrigable lands in Alberta are rather flat some quarter sections having only a foot or so difference in elevation between the headgate box and the farthest point to which water must be conveyed in the farm laterals. In these flat lands it is often necessary to run the laterals on a very flat grade in order that all of the land may be covered with water. To do this requires accurate levelling. Several different makes of small levelling instruments have been put on the market within recent years some of which are not sufficiently accurate for work on very flat lands. Much more satisfactory results are obtained when the laterals are located with an engineer's level.

*Use of the Level.* The level should be set up and levelled in the following manner. Carefully screw the instrument on the tripod which has been placed in position. Place the telescope diagonally across either pair of screws and bring the bubble to the center of the tube by means of the thumb screws, care being taken that the screws are moved in opposite directions. Then turn the telescope diagonally across the other pair of screws and bring the bubble again to the centre. This operation should be repeated until the bubble will remain in the centre during a complete horizontal revolution of the telescope.

Place the level rod with its bottom at the elevation of the water surface in the main supply ditch or headgate box, care being taken to have the rod plumb. Then sight through the telescope and note the figure intercepted by the horizontal cross-hair. For example we may assume that the cross-hair intercepts the figure 4.8 feet and that it has been decided to run the ditch on a grade of one-tenth of a foot per one hundred feet. Now measure off one hundred feet from the starting point, having one man hold the front end of the measuring tape or chain together with the level rod. A second man should hold the rear end of the tape. The rod is then held up by the leading man for a reading. As the ditch is to fall one-tenth of a foot per one hundred feet and a reading of 4.8 feet has already been observed at the starting point or station zero, 4.9 feet must be read at station one. By taking a sight on the rod for instance a reading of 4.7 feet may be observed, this indicates that the rod is being held at too high an elevation and it should be moved slightly downhill until the cross-hair of the telescope intercepts 4.9 on the rod. Conversely if a reading of 5.1 feet is observed the rod should be moved uphill until the 4.9 figure on the rod is intercepted.

To establish station two one hundred feet farther ahead, place the rod to read 5.0 feet indicating a fall of 0.1 foot from station one. Repeat this operation until four or five stations have been established when the instrument must be moved ahead approximately four or five hundred feet beyond the last station established. Then set up and level the instrument and take a reading on the rod

which has remained at the last point established. The reading may now be 5.6 feet, and the station to be established one hundred feet ahead must read 5.7 feet, the next 5.8 feet, and so on.

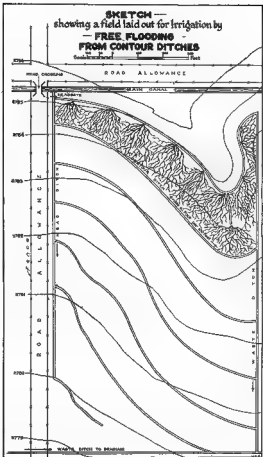
*Proper Gradient for Farm Laterals* - The average farm lateral as made with a plough and "V" ditcher is usually run on a grade of 0.1 to 0.2 foot per one hundred feet. Where it is necessary to keep the ditch "up" to reach some certain point flat grades, as low as 0.03 foot per one hundred feet are used. With these flat grades, however, the velocity of the water is so low that a large percentage of the total head is lost by percolation through the banks of the ditch and by evaporation. Sediment is deposited in ditches of this nature which also tends to decrease the flow. On the other hand ditches where grades are 0.2 foot per one hundred feet and upwards are apt to be subject to serious damage by erosion where the soil is light.

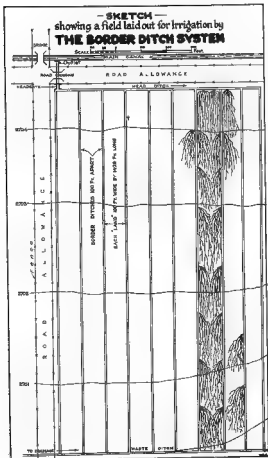
*Proper Spacing of Ditches and Reasons Therefor* - The distance between farm laterals will vary in accordance with the irrigation head available, the character and porosity of the soil, and the degree of smoothness of the ground surface. Laterals are often spread too far apart resulting in uneven depth of application, over-irrigation of land near the ditch and under-irrigation of the far edges of the land. On well graded land of gentle slope a good general rule to follow is to space the laterals one hundred feet apart where an irrigating head of about two and one-half cubic feet per second is available, one hundred and fifty feet apart where a head of three to four second feet is available, and not over sixty feet apart where there is only one second-foot available.

When applying the first irrigation with an inadequate head of water, to a thoroughly dried out, dusty field it is very discouraging to see the water spread only from one-half to two-thirds of the way across the land. The water soaking into and filling the soil near the supply ditch to the saturation point, is saving the foundation for serious trouble later on from a rising water table, alkali, etc. It is much better to have the ditches close enough so that light irrigations of uniform depth may be quickly applied. On old alfalfa fields and well established grass meadows the distance given may be increased about fifty per cent. Where the soil is very sandy or gravelly it will be necessary to decrease these distances, as the porosity of the soil and the slope of the land seem to warrant. The enhanced crop yields obtained as the result of light frequent irrigations of uniform depth, more than compensate for the additional area of land taken up by the close spacing of ditches.

## THE DIFFERENT SYSTEMS OF IRRIGATION AND THEIR APPLICATION TO ALBERTA CONDITIONS

*The Free Flooding Method, by Contour Ditches* - This method is still in more general use than any other, particularly in new projects, as it requires less grading than either of the other systems, and can be profitably used on slopes which are too steep for other methods and where the general topography of the tract is rolling. In general principle it consists in having a main supply ditch running along the higher side of the farm, or possibly along some ridge or high land, and from this head ditch taking off laterals which shall closely follow the contour of the land across the fields. The spacing between ditches is more variable than with the other systems on account of the different slopes encountered across the field. On steep slopes the laterals may approach as near as fifty feet apart, while, where the field gets flatter, they may be two or three hundred feet apart. This makes it difficult to apply water uniformly and a





one objection to this method of irrigation another is that the lands between ditches are irregular in shape, requiring more labour in harvesting the crop than in regularly shaped parcels.

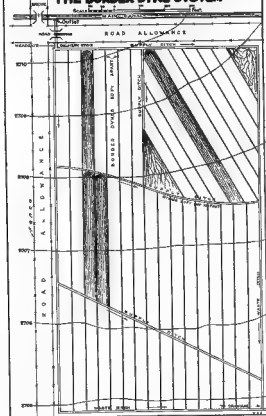
*The Border Ditch System.*—In this method the ditches are run straight across the field, parallel to each other and from fifty to two hundred feet apart, the distance depending upon conditions described under the heading "Proper Spacing of Ditches and Rows Thereof." The ditches are usually run down the slope of the land but may be run on the level across the slope where the fall of the land might cause excessive velocity of flow. Where the topography of the land is uniform this method is to be preferred to any of the free flooding methods, as with it the field is divided into rectangular lands. These lands are much more easily farmed than the irregular areas of the contour system. It is especially desirable to have the more important field crops, such as alfalfa and hay, watered by a rectangular system of ditches. In grain fields however, where the ditches are ploughed in before each harvest the necessity of having rectangular lands is not so imperative. With the border ditch system a more even application of water may be made than with either the contour or the border dyke systems. The water may be turned into the "land" from the border ditch on each side, allowed to run until the land for the length of a hundred feet or so has been covered, then by shutting the canvas dams, it may be turned into the land again farther down the slope, a being repeated until the land has been completely covered. This avoids the necessity of allowing the water to run for any excessive length of time over any part of the land such as is the practice with under the border dyke system, the water is turned into the land at the head of a border or when required turning or allowing it run there until it has spread the entire length of the border.

When conveying the water along the edge of the field from the head of one contour ditch to the head of another or between one border ditch and another, excessive slopes will frequently be encountered, but as the length of run is short the erosion will not be great enough to cause serious damage.



Use of Ridge for making Borders.—(Photo by Don. H. Bach)

**SKETCH —**  
 showing a field laid out for irrigation by  
**THE BORDER DYKE SYSTEM**



*The Border Dyke System.* This system is especially well adapted to the irrigation of permanent pastures and alfalfa fields. It is more costly to install than the other systems described and for that reason should not be used for grain fields which have to be ploughed up each year, as the ploughing destroys the small border dykes. After alfalfa fields have been established on land prepared for this system of irrigation very little work is necessary to properly irrigate. It lends itself very well to the use of a large head of water and permits of the entire field being cut as one unit as the harvesting machinery easily rides over the low broad dykes, thus materially reducing harvesting costs.

Essentially, this system consists of the division of the field into long narrow strips of land by means of low flat levees which usually extend in the direction of the greatest slope and confine the water to a single strip of soil. The bed of each strip should be carefully graded to a uniform slope transversely so that when a sheet of water spreads down the land it will not tend to flow to either edge of the strip. The small levees are made either with a Fresno scraper or an implement termed a "Ridger" (See illustration). The levees are first marked



Large Machine Ridger made by the Canada Land & Irrigation Company

out by lines of stakes, then about two furrows each way are ploughed and thrown together to make ridges. These ridges are then gone over with the "Ridger" which gathers an additional amount of earth from an area six to eight feet wide on each side of the ploughing and traps it up behind making the levees or ridges. These levees are then gone over lengthwise with a harrow to smooth them down so that when completed, and after settling they will be about six inches high, five feet wide and rounded over. Levees are spaced from thirty to sixty feet apart, usually about forty feet on average smooth land, but may be spaced closer where the slope of the land is great or the soil very porous. These borders may vary in length from four hundred to one thousand feet, depending upon the porosity of the soil, the slope of the land and the irrigation water available. With a head of about three second-feet they should be between four hundred and six hundred feet long for average loam soil. As the available

irrigation head is increased, the length of the borders may also be increased. In sandy soil the length of the borders must necessarily be much less. Head ditches are run across the fields to supply the borders.

The levees may also be made with Fresno scrapers, sufficient earth to make the levees being obtained by skinning the surface of the borders with the Fresno. The scraper teams begin at the head ditch and work down, crossing and recrossing the border at right angles to the levee, the scraper being dumped as it passes the line marked out for the levee. After the levees have been made by this method the border or 'land' should be thoroughly floated and levelled transversely.

Where sufficient water is available, say ten to twelve second-feet, one man can irrigate up to thirty acres in a twelve-hour shift by this method. Permanent headgates should be constructed capable of turning large heads of water into each border.

*The Farrow or Corrugation Method* The corrugation system is used almost exclusively in the older irrigation districts of southern Idaho, U.S.A., where the



Home-made Corrugator

soil is a fine clay loam which runs together puddles when wet and bakes and cracks when dry. Flooding this type of soil by any of the free flooding methods tends to puddle the top layer of soil, which becomes quite hard when the moisture has evaporated. This puddling and baking process injures alfalfa, and it is with the object of preventing this that the corrugation system has been used so extensively.

When fields are irrigated by this method some streams of water are allowed to run down the corrugations for several hours, soaking the subsoil and spreading laterally by capillarity, meanwhile leaving the surface of the soil comparatively dry.

Irrigation by the corrugation method is especially desirable when a light, easily washable soil has been seeded to alfalfa or clover, as surface flooding would wash out many of the seeds. By running water down the furrows the soil between them is soaked by capillarity and the tiny seeds are not disturbed.

The length of the furrows should vary with the soil type and the slope of the land from six hundred feet in medium to two hundred and fifty feet in very sandy soils.

The corrugations are usually made with an implement called a corrugator (see illustration) and are spaced about thirty-two inches apart, although this distance may be decreased to sixteen inches in heavy impervious soils. These corrugations which are supplied with water from head ditches spaced from three hundred to five hundred feet apart are laid out across the field as nearly parallel as possible on a grade of from two to six inches per one hundred feet in the direction of the greatest slope of the land. Where the slope exceeds the allowable grade for a soil the corrugations must be laid out on a line across the slope. Checks or a *Y* in the form of small gates are placed in the head ditches. These gates may be either wholly or partially closed to maintain the water at a desirable height in the ditches. The water is let out of the ditches into the corrugations through small pipes sixteen to twenty-four inches in diameter made of four



"V" Ditcher in Operation

latins nailed together which extend through the ditch bank. These pipes should be placed in the ditches while they are full of water so that the joint of each pipe may be at the same distance about three inches below the surface of the water in the ditches, thus ensuring an equal quantity of water being discharged through each pipe. The flow of each pipe may be regulated amongst several corrugations. The advantages of the corrugation system are first that the water is evenly distributed evenly, and, second, that there is always a great loss by deep percolation especially where the corrugations have too great a length between head ditches.

*Construction of Farm Laterals.* After the location of a farm lateral has been determined and marked with a line of stakes the lateral may be constructed with either a walking plough and "V" ditcher or with a ditching grader.

Laterals are constructed with the plough and "V" ditcher as follows. A furrow, six inches deep is opened out along the line of stakes. The team is then turned and driven back over the furrow just ploughed. The plough is

placed in the bottom of the first furrow ploughed, and so adjusted by means of the clevis, that it will turn out a second furrow six inches deep, in the same line but immediately underneath the first furrow. This method makes a rough ditch approximately one foot deep and ten feet wide with the earth ploughed out evenly on both sides. The ditch is completed by hitching a heavy team to the 'V' ditcher and pulling it through the rough ditch about twice on each side to smooth down the banks and throw out the loose earth. A four-horse



Machine Ditcher



Machine Ditcher

evener is used, with a horse hooked at either end and the inside reins lengthened out about three feet, so that each horse may walk on the outside of the ditch bank. One man stands on the point of the "V" and drives the team. A second man walks outside the ditch and by means of a long handle fastened to and in line with the smoothing blade of the "V" keeps it at a constant angle. This method makes a smooth "V" shaped ditch with a carrying capacity of from one to two cubic feet per second. To make a larger ditch with the wooden "V" such as would be used for a flow of from two to four second feet of water, it is necessary to bank the team to the plough by means of a leg chain and rise the plough, taking an additional furrow or so from the bottom of the ditch as constructed above and running the ditcher through once or twice after the second ploughing. Where a steel "V" ditcher is used it will usually cut the ditch deep enough by making several rounds without any more than the first ploughing.



Large Ditching Plough

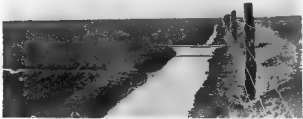
The "Martin ditcher" is made on the same principle as the ordinary "V". It is of steel construction throughout and being much heavier than the wooden "V" requires six horses for its operation. It cuts much deeper than the wooden implement and makes a better ditch. Very good ditches have been made by towing a Martin ditcher behind a Ferguson tractor.

The points to remember for making straight ditches with good water-tight banks are —

- (1) The two plough furrows must be made in the same vertical plane, not side by side.
- (2) The angle of the cutting blade of the ditcher must be regulated by a man walking outside the ditch. It is not possible to make continuous uniformly sloping banks by endeavouring to control the ditcher while riding the rear end.

- (3) The ditcher should be pulled through the ditch at least twice each way, this fills up the small holes in the banks and makes the banks higher and more substantial.
- (4) The sides of the ditch should have a slope of about forty-five degrees.

Weak places will frequently be found at points where the ditch crosses "barn-outs" or suddenly changes direction. These places should be reinforced until they are as strong as the remainder of the ditch. Very deep depressions or coulees will necessitate work with teams and scrapers, and in extreme cases the construction of a flume.



Diverting Water with a Canvas Dam

*Applying the Irrigations*—It is well to study irrigation problems in advance. A schedule should be drawn up showing how many irrigations each field is to receive, the dates upon which each is to be irrigated, and the depth of water to be applied per irrigation. This plan will enable the season's irrigation work to be seen as a whole. Knowing how much water to expect, and the labour available, the work can be arranged so as to economically irrigate the different crops. This is much more satisfactory than dealing with the problem in a haphazard manner as the necessity arises and without any pre-arranged plan.

*The Use of the Canvas Dam*—The canvas dam is absolutely indispensable. The irrigator should have several. These are usually made from twelve-ounce to twenty-ounce canvas, and should be about four feet wide and six feet long, but may be larger for larger ditches. The six foot side is fastened by a 2- by 2 inch scantling either by nails through a lath, or by folding the canvas over the pole and sewing it together thus making it possible to withdraw the pole and fold the canvas when not in use.



Use of Canvas Dam

This dam is used to divert water from the various laterals to the land. It should be put in place before the water reaches the point of diversion and should be about one-third of the way up the ditch extending up stream and the poles spanning the ditch and resting in each bank. As the earth should be thrown on the canvas to hold it in place. The laterals should then be opened at one or more points as desired to distribute the water on the land.

In cases where the border laterals are one hundred feet apart, the water should run on the land until it has covered approximately two hundred feet down the border this distance varying according to the position. It should be

a second dam should be set farther down the ditch. When the water has spread down the land to a point opposite the second dam the first dam should be removed thus allowing the water to run down the ditch and be diverted by the second dam. This process is repeated down the length of the border until the entire land has been watered.

*Points to be Noted in Irrigation—*

- (1) Never attempt to irrigate too great a length of land from one "set"; it will over-irrigate the land near the dam and cause too great a loss of water by deep percolation.
- (2) After a dam has been removed and the water allowed to run down to the next set, all openings in the ditch banks used to allow the water to run on the land from previous sets should be closed. Failure to do this causes loss of irrigating head and over irrigation.
- (3) Care should be taken that all dry spots are reached and that no area capable of irrigation is left unwatered in the vicinity of the set. Small ditches should be made with the shovel to lead the water to such points as are not readily flooded by the flow diverted by the dam. The damage caused by these small ditches will be negligible when compared with the increased yields due to the thorough and uniform distribution of the water.
- (4) It is always best to start at the upper end of a "land" and irrigate towards the lower end.

*Applying the Correct Depth.* In order to apply the correct depth per irrigation and thus effect the greatest economy in the use of water, the area of land to be irrigated must first be ascertained.

The area in acres of any rectangular piece of land may be closely approximated by multiplying the number of paces (yards) in length by the number of paces in width and dividing by 4840. Where the land is one hundred feet wide between parallel ditches, a length of one hundred and forty-five paces equals one acre.

The irrigating head, or quantity of water in cubic feet per second flowing down the ditch may be measured by weirs or flumes, or in the ditch near the point of diversion on to the land. The most accurate measurement can be secured with weirs, but a very close approximation of the discharge can be obtained by multiplying the area of the wetted cross section of the ditch by the velocity of the flowing water in feet per second. For example, assume a field of ten acres, divided into lands by ditches one hundred feet or thirty-three and one-third paces apart. These "lands" on being paced out measure two hundred and ninety paces in length. Then  $291 \text{ paces} \times 33\frac{1}{3} \text{ paces} = 2 \text{ acres}$ . The

4840

irrigating head is then determined by any of the methods mentioned above, to be, say three cubic feet per second, usually described as "three second-feet." One second foot will deliver one acre-inch of water in or in twenty-four hours will cover an acre to a depth of twenty-four inches. Therefore three second-feet will deliver three acre-inches per hour. Assume that the crop grown is grain and that it has been decided to apply to it a six-inch irrigation. This means a depth of six inches of water on each acre or a total depth of twelve inches for each "land." The irrigating head will deliver three acre-inches per hour, hence it should take twelve divided by three or four hours to irrigate the two acres, or two hours per acre. Knowing that each land should be irrigated in four hours, or two hundred and forty minutes it follows that it will be necessary to cover a length of fifty paces about every forty-one minutes. The operation should,

therefore, be regulated accordingly. Where it takes a longer time to cover the land than has been calculated, it will be apparent that more than the correct depth is being applied.

It will be found in actual practice that many factors such as condition of soil, roughness of land, stage of crop growth, and method of seeding, will have a marked influence on the degree of exactness with which the irrigation program can be carried out. Nevertheless, the man who knows just how much water is wanted on each field, and exactly how it can be applied most economically, will get through the irrigation program most expeditiously and the land will be left in better condition for crops than where the water is allowed to run until the soil has the appearance of having received enough.

It has been found that a single disc press drill is a great aid in distributing irrigation water evenly. This may sound unreasonable but is nevertheless true. This type of press drill leaves the seed bed covered with small well defined corrugations about two inches deep—a depression where the press wheel has compacted the soil over the seed, and a ridge of earth thrown up between the seed rows by the single disc. When the seeding is done in the direction of the greatest slope of the land these small corrugations act as tiny ditches in distributing the water. An experiment was carried out at the Brooks Experimental Station, where (a) peas were sown three inches deep with the press drill, the rows running down the slope, and (b) where the peas were sown with the ordinary drill and harrowed afterwards. Much better yields were obtained in (a) than in (b). It was found that the harrowing left the land too smooth. The water spread over the surface too fast, and instead of running down the land as it did where the press drill was used, ran too much across the land and wasted along the farther ditch edge.

**Night Run.** In the irrigation of large fields it is frequently necessary to let the water take care of itself especially through the night. At best this is a wasteful and unsatisfactory method of irrigating but as it is frequently impossible or undesirable to shut the water off when the irrigator goes to bed at night, a few hints as to how the phase of the situation can be handled may not be amiss. Experienced irrigators will select for the night run those lands which have the most uniform topography where there will be the smallest loss from surface run-off. The water should be turned on the land in several places and dams put in the lower ditches so as to catch the overflow from the irrigated lands and re-divert this waste to irrigate other lands. When the irrigator returns next morning and inspects the fields, he will probably find numerous spots which the water has missed. These spots should be watered before moving to other lands.

## SECTION 2

## IRRIGATION INVESTIGATIONS

*Outline of Work.* It is a discouraging fact that even if the maximum facilities for storage are provided and the most careful use is made of the available water there will not be sufficient to irrigate more than 3,000,000 acres, or about ten per cent of the land requiring irrigation in Alberta and Saskatchewan. To provide reservoirs for this limited supply and to so conserve and use it at all times that the greatest benefit may be derived by the greatest number are tasks that to-day challenge the West.

In the early years of irrigation in Canada the streams carried a surplus of water and irrigation suffered through lack of water. It is to their credit with lavish expenditures of credit to build the farmers of the Irrigation Act who, learning from the unfortunate experience of the Western States and looking to the future when every drop of water should be needed provided in the Act that a law should be passed upon the quantity of water that might be appropriated and use per irrigable acre. This was set out in irrigation systems or sufficient to cover each acre to the depth of two feet measured at the point or points of delivery to any farm and was considered to be sufficient for the average needs of crops in Western Canada and this quantity was considered as the legal limit of water. In recent years it became apparent that even this was an excessive quantity of water for some crops and the duty was therefore increased to one and one-half acre feet per acre and the duty of work that a unit quantity of water is required to do was increased.

Thereafter the duty of water as to volume of water that is required to produce a crop is not quite so simple. It takes a great deal more of water to produce the same crop but as might be expected it varies widely for different crops and also climates. The significance of this fact can only be appreciated by those who know how enormous irrigation water is applied in the West and an enormous saving of water and increase of production is made by the use of water-gates and known as water-measure. It is most water be should use for each particular crop and soil and should apply according to scientific rather than common-sense rules. Such an idea could be put into effect never be fully attained but it is the toward which crops irrigated should strive.

As the Minister of the Interior is responsible for the administration of the surface water supply of Alberta and Saskatchewan and particularly as he must define the duty of water and the water requirements of crops according to soils and climate, it water investigations were commenced several years ago from the results of which it is now possible to draw conclusions of great value and interest. These investigations were undertaken for the purpose of securing reliable data relative to,—

- (1) The amount of water required to produce the maximum yield of specific crops when grown under varying conditions of soil fertility, soil texture and climate.
- (2) The proper depth of water to apply per irrigation for different soil types and for different crops.
- (3) The relationship between the "irrigating head" and the distance between the distributing ditches.
- (4) The seasonal water requirements of various crops and the time when irrigation water should be applied.
- (5) The amount of water supposed to be wasted from and used on the farms of a typical local irrigation project.

The first experiments were conducted in 1913 on small plots set aside for the purpose by farmers in the Cardston district.

In 1914 a tract of some forty acres was secured at Strathmore where duty of water investigations were carried on in co-operation with the Department of Natural Resources of the Canadian Pacific Railway Company. This station was operated until 1917 when it was abandoned owing to the rise of the ground water level so near the surface as to materially influence the yields of the various plots by sub-irrigation thus rendering unreliable any data obtained from the application of different quantities of water.

In the year 1914 a tract of some twenty three acres was secured from the Canada Land and Irrigation Company at Rosedale where investigations were carried on co-operatively with the company until 1921 when the station was abandoned in favour of a more desirable location on the company's farm near Vauxhall.

During 1915 and 1916, a program of irrigation demonstration work was conducted in the Strathmore and Caledon districts. Irrigation specialists working in co-operation with the farmers demonstrated irrigation methods and advised the farmers regarding the amount of water needed by crops and the most economical depth to apply per irrigation.

In 1917 the Dominion Duty of Water Experiment Station was established on a forty-acre tract of land leased from the Canadian Pacific Railway Company situated one and one half miles west of the town of Brooks. The most reliable and complete experimental data have been secured from this station because the experiments were most more carefully planned and carried out than was possible at either Strathmore or Rosedale.

Thus since 1913 the Research Section has been gathering at Cuthbert Strathmore, Rosedale and Brooks information regarding the duty of water for a variety of crops under climatic and soil conditions which are typical of different parts of southern Alberta.

The definite knowledge which has thus been obtained of the proper amounts of water to apply to crops clearly indicates that the past and present practice of applying water lavishly does not pay. It wastes water, tends to produce a hard and water logged soil and in the end results in greatly reduced yields. The problem now is to convince irrigators of the necessity to limit the quantity of water used per acre to that which is indicated and the water table must be made available to distribution to crops. The recent decrease of the duty of water from two acre feet to one and one half acre feet per acre has had the effect of increasing the available supply nearly thirty three per cent and further economy in the administration of water will result when it becomes possible to define for each large irrigation project the duty of water that will best satisfy its requirements.

*Duty of Water.* The factors which directly influence the water requirements of any crop are: the physical properties of the soil and subsoil, the fertility of the soil, the size of the irrigating land, the depth applied per irrigation, the preparation of the land, and the climatic conditions.

*Physical Properties of the Soil and Subsoil.* Soil texture has a greater influence on the duty of water than any other one factor. In the more porous soils, such as light sands or gravel, serious losses of water occur by deep percolation. When an attempt is made to run a relatively small head of water across a "land" where the soil is very porous, the downward movement of the water is so rapid in comparison with its lateral movement over the surface that either the subsoil becomes saturated before the surface area to be watered has been fully covered or the downward movement of water becomes so extensive as to stop the lateral or surface movement entirely.

In the heavy or less porous soils the extent of the downward movement of the water in comparison with its movement over the surface, is much less than

in the light soils. Consequently a heavy type of soil will permit of the ditches being spaced much farther apart than when using the same irrigating head on a more porous soil.

Soil moisture investigations show that the light sandy soil at the Strathmore station under free sub-drainage conditions holds a maximum amount of but one to two inches of available water per foot in depth while the heavier clay loam soil at the Brooks station under the same conditions, holds two and one-half to three and one-half inches.

Assuming that the irrigating head, length of run and width of land between ditches are similar and taking into consideration the water-holding capacity and rate of percolation peculiar to each soil type, it would be found that by the time the heavier soil had been filled to capacity and was holding from ten to fourteen inches of water in the four foot soil column the lighter soil would not only have reached its maximum holding capacity of from four to eight inches but would actually have lost some six inches of water by percolation below the four-foot depth.

Moisture moves through the soil by capillarity in all directions as influenced by the combined forces of gravity and surface tension of liquids. This movement is usually upward or towards that point where moisture is being drawn from the soil either by the roots of plants or by evaporation at the surface. The rate at which water moves through the soil by capillarity is never very rapid when compared with the movement of the greater volume of water downward by gravity. The rate of capillary movement is influenced by the arrangement and size of the soil particles; the coarser the soil particles the shorter will be the distance the moisture can rise, hence a coarse sandy soil not only has less water holding capacity than a heavy soil but returns a smaller portion of its water to the surface by capillarity.

Crops grown on the sandy soil of the Strathmore station were observed to be "burning up" or "drying out" more than crops even when the water table stood at a depth of only six feet below the surface.

To irrigate very porous soils with the least possible percolation loss requires that the distance between distributary ditches and the size of the irrigating head be so proportioned as to permit of the application of light irrigations. To do this it is necessary that the irrigating head be larger in comparison with the distance between ditches than would be the practice in the heavier soils.

**Fertility.** It is a proved fact that the more fertile the soil the less water will be required to produce a given yield; therefore the duty of water for any specified yield per acre will vary as the soil is rich or poor in available plant food.

The effect of fertility upon the water requirements of crops was very convincingly demonstrated by an experiment carried out at the Brooks station during 1920. Banner oats were grown under four different conditions of soil fertility. A total depth of 1.75 feet of water produced yields ranging from one hundred and thirty two bushels per acre where the preceding crop was clover down to eight-two bushels per acre where three other grain crops preceded the oat crop.

**Size of Irrigating Head and Depth Applied per Irrigation.**—The average irrigating head used in the Coalville district as calculated from the results of water measurements made on some twenty farms in this district during the past five years is 2.27 cubic feet per second. As a general rule very few irrigators care to work with a size of irrigating head than this the majority preferring a second foot or so additional. A head of from two or three cubic feet per second is about as that one irrigator can handle to advantage on most fields where very little levelling work has been done and where the water is

applied by the free flooding system. Where the land has been levelled and laid out in either the border dyke or border ditch system, much larger heads can be used.

Irrigation experiments conducted at Brooks, Romanae and Coalsdale with cereals, have demonstrated that only in cases of extreme soil water exhaustion is it practical, or economical to apply irrigations in excess of six inches per application. The best results have been obtained where the water was applied in four and six inch irrigations. Twelve inches of water have usually produced better yields of grain when applied in three irrigations of four inches each than when applied in two irrigations of six inches each. In order to apply light irrigations comparatively large irrigation heads should be used, with ditches



Making Ditches at Brooks Experimental Station

Note arrangement of double-trees, rein spreaders handle and men to make efficient ditches with steel "A" ditcher. The man holding harness walks outside of ditch.

relatively close together, so that the water may be flooded across the land quickly. A common practice in the Coalsdale district is to apply to grain fields two irrigations each of about nine inches depth during the growing season. This is not an economical practice, it tends not only to water log the soil but also to leach out the available plant food. Much larger yields could be obtained if the eighteen inches of water were applied in three irrigations instead of in two.

As explained previously, it is only under the very driest conditions that more than a four-, or at best a six-inch irrigation can be entirely retained in the upper portions of soil, penetrated by the roots of the plant, or the root zone.

Light frequent irrigations will do much to lower the total amount which must be applied to crops to produce maximum yields and the use of large irrigating heads in comparison with the width of lands across which the water is to be spread, will facilitate the application of these light irrigations.

*Preparation of the Land* - Where the land has been well levelled it is comparatively easy to apply quickly an irrigation of uniform depth to all parts of the field with little surface or percolation loss. Where attempts are made to irrigate rough, rolling land that has not been levelled a great loss of water occurs, the high areas receiving little if any water, the low areas receiving an excessive amount hence losing water by deep percolation. Water is also lost down the surface gullies and depressions of the land.

## SEASONAL WATER REQUIREMENTS AND TIME OF IRRIGATION

*Water Used to Grow the Crop* - Water introduced into the soil, either as irrigation or as rainfall to supply the growing crop, is extracted or lost from the soil zone occupied by the plant root system by transpiration, percolation and evaporation. This combined loss represents the losses that of necessity occur in field practice and is the amount of water required to produce or grow the crop. It is referred to herein as "Water used to grow the crop" or "Depth Used."

*Transpiration* - Water is needed by the plant to maintain the turgidity of its cells; whenever the water supply is insufficient the cells become flaccid and the plant withers. Water dissolves the various foods made or stored in the plant and conveys them to the different organs of the plant needing nourishment. It brings into solution the plant foods present in the soil and conveys them through the roots to other parts of the plant where they are stored. It forms more than one half the total weight of the plant, is the chief ingredient of the cell sap, and is used to some extent as a food.

The absorption of water through the root hairs is the only means a plant possesses of obtaining its supply of water and food. Most of the water secured by the plant through its roots is lost to the surrounding atmosphere through small openings on the underside of the leaves. This use or loss of water from the soil through the plant is termed transpiration.

The amount of water a plant will transpire at any stage of growth will depend upon: (a) The amount of water held in the soil zone occupied by its root system; (b) the amount of energy as light and heat received from the sun; (c) the relative humidity of the surrounding atmosphere as influenced by winds; (d) surface evaporation and shade; (e) the area of its leaf surface and the extent of its moisture absorbing root surface; and (f) the fertility of the soil or the concentration of the soil solution in available nutrients.

*Percolation* - The amount of water that is lost to the plant by percolation below the soil zone occupied by its roots will depend upon: (a) the texture of the soil, whether coarse and of low water retaining capacity as of sand, or fine and of high water retaining capacity as of silt or clay; (b) the amount of water held in the root zone at the beginning of the season; and (c) the depth applied and frequency of irrigation.

*Evaporation* - The amount of water lost by evaporation from the soil surface is influenced by cultivation and shade of plants, temperature, humidity, sun's energy and the amount of water in the soil. Many of the forces that influence the amount of water used in growing a crop are not within our control, such as temperature, humidity, light, general soil texture and to a great extent, leaf surface. The losses caused by the variation of the moisture content of the soil can however be controlled by correct irrigation practice, the losses influenced by varying soil fertility by the use of the proper system of crop rotation, and the losses due to evaporation and extent of leaf surface by reasonable farming operations.

**Optimum Moisture Content**—Experiments conducted at the Brooks Station indicated that the most favourable moisture conditions for growth were obtained when the pore space of the soil contained the following proportions of water: for a sandy soil 27 per cent, for a silt-loam soil 41 per cent, for a clay-loam soil, 53 per cent.

When the moisture content was above the optimum per cent the excessive water not only lowered the soil temperature but cut down the air supply to the roots. When it was appreciably less than the optimum per cent the moisture films were held to the soil grains with such force that the roots hairs could not secure water in sufficient quantities to maintain normal growth. When the soil is too wet the development of the plant as a whole is retarded because the roots cannot grow as they should for lack of air and warmth. When the soil is too dry, root development is retarded because the plant as a whole cannot get enough water.

The amount of water obtained by the plant from any soil zone or layer is in direct relation to the development of actively absorbing rootlets in that zone, as the movement of water by capillarity from one soil zone to replenish that abstracted from another zone is too slow to supply the needs of the roots. To secure an abundant supply the roots must grow to the water.

Diagram No. 1 shows the amount of water used by wheat and sugar beets through the different stages of their growth when the soil moisture of the root zone was maintained at the optimum content and indicates the time and depth of irrigation it would be necessary to apply as a supplement to the rainfall to provide the crop with the amount of water required, each month or during each period of growth. Upper graphs show the seasonal use of water by wheat. Upper left graph gives results obtained in 1923 on a silt soil and shows a use of 3 inches in May, 6 inches in June, 7 inches in July, and 6 inches up to August 27 when the crop was harvested, a total depth used of 22 inches. Upper right graph gives the results obtained in 1925 on a sandy soil and shows a use of 2 inches in May, 8 inches in June, 12 inches in July, and 5 inches up to August 7th of August, when the crop was harvested, a total of 27 inches. The dotted line in the lower right of upper graphs shows the height of the wheat at any time during its period of growth. During the period in June the grain was 6 inches high until harvest the 1923 crop used water at an average rate of .245 inch per day, the 1925 crop at an average rate of .315 inch per day. The more rapid rate of use of water by the 1925 crop may be attributed to a lighter and warmer soil, more favourable weather during the period of maximum soil surface and a slightly greater proportion of loss due to the lower capillary water holding capacity of the lighter soil.

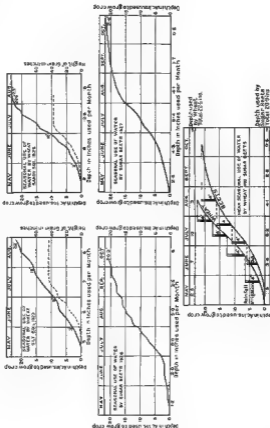
Middle graphs show the seasonal use of water by sugar beets during 1926 and 1927. In 1926 the crop used 1.2 inches in May, 2.0 inches in June, 5.0 inches in July, 5.0 inches in August, 3.5 inches in September, and 0.5 inch during the six days in October, a total of 17.2 inches. In 1927 the crop used 2.6 inches in May, 4.3 inches in June, 8.4 inches in July, 4.1 inches in August, 1.7 inch in September, and 0.5 inch during the twenty-two days in October, a total of 31.6 inches.

Lower graph shows by curves the mean seasonal use of water by wheat and beets and by vertical columns the approximate date and depth of irrigation necessary to provide the crops with the requisite amount of water when the rainfall was from 4 to 6 inches during the period of growth, or about 1 inch effective rainfall per month.

Wheat requires 22 inches of water. With a rainfall of 3 inches during growth irrigation would be required as follows: 4 inches May 23, 4 inches June 20, 4 inches July 10, and 4 inches July 24.

SEASONAL USE OF THIS ARTIST'S - ILLUSTRATED WATER PUMPING AND RECLAMATION SERVICE

# SEASONAL USE OF WATER BY WHEAT AND SUGAR BEETS



Beets require 20.9 inches of water. A light irrigation of about 2½ inches June 10 and 4 inch irrigations on July 3, July 20 and August 13, in addition to 1 inch per month effective rainfall would supply the water requirements of this crop.

The preceding diagram shows that the water requirements of wheat were greatest during June and July. For sugar beets the water requirements were greatest in July and August.

Maximum crop yields are obtained under conditions where the best or optimum soil moisture content is maintained throughout the growing season. To maintain this optimum moisture content it is necessary to apply the irrigations more frequently during that period of the growing season in which the daily water consumption is greatest.

Throughout southern Alberta there is usually sufficient water in the soil, when supplemented by spring rains, to supply the few inches needed up to the 15th or 20th of May; the bulk of the irrigation water must then be applied in June and July. Alfalfa, peas, potatoes and beets will need a further irrigation in August.

On each of the following diagrams Nos. 12 to 18) is a schedule showing the number, depth and average time of application of the irrigations received by each plot in the crop series. The diagram gives the yield produced per acre with from 1 to 6 irrigations. The schedule gives the time these irrigations were applied.

#### PLANNING AN IRRIGATION SCHEDULE FOR THE FARM

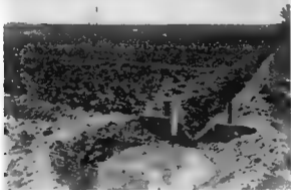
The water user will find it economical and profitable to plan an irrigation schedule for each of the different crops grown on his farm under the ditch and then to so arrange his ditches, labour and water deliveries as to expeditiously carry out the schedule. For example, the maximum yields of wheat at the Brooks Station (Diagram No. 2) were produced when four 4 inch irrigations were applied in addition to a rainfall of 5 or 6 inches between April 1 and August 31. The average date of application of these four irrigations as shown on the irrigation schedule for wheat was June 5, June 25, July 12 and July 25. The crop thus received 22 inches of water during the growing season, 16 inches as irrigation and 6 inches as rainfall. If the average April to August rainfall in the Water User's district is 10 inches then he should plan to apply but three irrigations, should the rainfall however be but 4 inches during the above period he should plan to apply five irrigations. If at the time of a scheduled irrigat. the effective rainfall since the last irrigation has amounted to 4 or more inches then that irrigation should be omitted. On the other hand if a waiting 4 inch irrigation is delayed until the moisture content of the soil has been reduced to the point where the crop is suffering it is often too late to water the field before serious damage occurs. This is especially true where large areas are farmed. It is much safer to irrigate well in season and have a supply of water stored in the soil against further needs.

Diagram No. 17) shows that the maximum yield of alfalfa per acre was obtained when the crop received five 6 inch irrigations in addition to a rainfall of 6 inches between April 1 and date of last cutting. The irrigation schedule shows that these irrigations were applied May 20, June 10, June 30, July 13 and July 27. The water user may use this same schedule for his alfalfa if the rainfall in his district during the above period is six inches. If more than 6 inches and less than 12 inches, but four irrigations will be required.

The above examples give the water requirements to produce the maximum yields per acre. The diagrams and irrigation schedules give the irrigation treatments that produce the maximum and less than the maximum yield of the crop series.

Plants find conditions most suitable for growth when the soil pore spaces contain the proper proportions of air and water as explained under the heading of "Optimum Moisture Content." As the amount of water used to grow the crop increases due to increased temperature heat surface evaporation etc. the amount of water that must be supplied to the soil to maintain this optimum content increases. The water user should therefore know the amount of water his various crops will need each month and what part of this need has been supplied by rainfall and then so regulate his irrigation the additional amount required.

An adequate supply of moisture is required during that period in which the crop is making its most rapid growth. If the supply is not available the grain will not properly fill out. But the greatest importance is an adequate supply of moisture early in the season if this is lacking a poor stand of grain will result. It is in the early part of the season that the plan "takes stock" of



"V" Notch Measuring Weir

the water it has available and arranges its life accordingly. A crop started from early drought will never produce as much as if it had always enjoyed optimum growing conditions.

In many districts of southern Alberta during the period 1918 to 1921 it was so dry in the spring that the soil at the time of seeding did not contain enough moisture to germinate the seed and no growth was made until the fields were irrigated. As it requires about one hundred and ten days for a crop of Marquis wheat receiving all the water it needs to mature it can be readily understood that if this crop did not begin to grow until tardily irrigated, perhaps not until June, it would be going through its normal life span mature nearly as much later as its germination had been delayed.

At the Brooks Station the heaviest watered grains matured well in season, providing they did not suffer from drought at any time. Crops seeded April 20 were ripe by August 15.

## DUTY OF WATER INVESTIGATIONS AT THE BROOKS EXPERIMENT STATION 1918 TO 1927, INCLUSIVE

The soil at this Station is in general, a mixture of silt and very fine sand, quite uniform to a depth of 12 or 14 feet where a narrow layer (6 inches) of fine gravel is encountered. On the highest knolls of the farm the silt is covered with medium fine sand while in the lower lying part of the farm the soil becomes somewhat heavier. It has a very high water holding capacity. Data for this soil are presented under "Salt Loam" in the table in Section (3) of this Bulletin. The land to be used for experimental work was broken to a depth of 3 inches during June, 1917, and back-set to a depth of 7 inches the following September. It was then levelled with fresno scraper and float. All permanent structures, weirs, roads and buildings were completed during 1917. The first



Two-way Plough

seeding was done in the spring of 1918. Plan (at end of report) shows, in general, the layout of plots and in detail, the location of the various rotations for the 1921 season.

**General Cultural Methods Employed.** All lands were ploughed with a two-way plough. This type of plough has proven very satisfactory for use on irrigated fields as with it the furrows are all thrown the same way, thus leaving no dead or back furrows to hinder irrigation. After ploughing, which is usually done during October, the land is harrowed and floated and left ready for seeding the following spring. The seeding is done with a press drill. The advantages of this type of drill are explained elsewhere in this bulletin. Directly after seeding, ditches are made with a walking plough and steel "V" ditcher.

The irrigations are applied according to schedule. The water is measured by means of weirs, distributed over the farm at convenient places. Grain crops are harvested with a 5-foot cut binder, forage crops with mower and rake.

Soil moisture tests are made in each plot at the time of seeding or beginning of growth in the spring and again at the time of harvest in order that the

amount of water in the soil at the beginning and end of the season's growth may be ascertained. All grain plots are double disced following the binder.

**Rotations**—In planning the work to be done at this Station it was decided to ascertain the water requirements of peas, wheat, oats, barley, flax, alfalfa, clovers, grasses, potatoes, corn and sugar beets. As grains are grown under many conditions of soil fertility it would serve no definite purpose to merely obtain duty of water data for general or average fertility conditions. It is essential that the water requirements of grain be ascertained not only where grown under the most favourable, but also where grown under medium and poor fertility conditions, as the water required to produce a given yield per acre varies considerably with fertility. Further, where data are desired covering a period of years on grain growing under a definite condition of soil fertility, it is evident that some provision must be made to ensure that this condition will be maintained each year with as nearly as possible the same potentiality for crop production. A rather comprehensive system of crop rotations was, therefore, planned to ensure the stability of the condition as above described.

#### SCHEDULE FOR ROTATIONS

Rotation (A), Alfalfa five years, potatoes, wheat, flax

Rotation (B), Alsike clover, four years, roots, oats, wheat, oats

Rotation (C) Grass three years, potatoes, barley, wheat

Rotation (D), Red C<sup>o</sup> over two years, oats, barley

Rotation (E), Peas, wheat, oats, barley

In 1926 Rotation (A) was changed to alfalfa five years, beets, beets, beets.

#### WATER REQUIREMENTS OF WHEAT

*Diagram No. 2* shows by column graphs, the water requirements of Marquis wheat under three conditions of soil fertility, high, medium and low, and by curves the influence of soil fertility on the depth of water used per unit of yield.

The first column in each graph represents the yield per acre produced by the April 1 to harvest rainfall alone. The next six columns represent the yield per acre produced by the application of from one to six irrigations of four inches depth each, in addition to the rainfall. The last three columns of the graph represent the yield per acre produced by the application of from two to four irrigations of six inches depth each in addition to the rainfall.

The number and depth of irrigations applied to any plot are shown immediately under the rainfall, and a vertical line with the heavy column above which represents the yield for that particular plot. The bottom of any irrigation column indicates the total depth of water received (irrigation plus precipitation) by that plot. The total depth of water used to grow the crop is shown by the dotted line and is that amount of water which has been used or lost from the soil to a depth of six feet, by transpiration, evaporation, and percolation, it is determined by adding to the calculated water content of the soil at the time of seeding the amounts received in the form of precipitation and irrigation and deducting from the sum of these amounts the amount of water remaining in the soil at the time of harvest.

The more important points shown by these graphs are —

(a) The total depth of water received when produced the maximum yield per acre where the crop was grown under varying conditions of soil fertility.



(b) The crop producing powers of a given quantity of water under varying conditions of soil fertility

(c) The water used to grow the crop, together with the amount stored in and used from the soil to a depth of six feet.

(d) The relative crop producing value of irrigation of different depths per application.

*Total Depth Received*.—The maximum yield was produced with a total depth received of 1.78 feet in high fertility, 2.17 in medium fertility and 2.00 in low fertility. Average 1.97 feet.

*Total Depth Used*.—The water used to grow the crop on any plot is indicated by the position of the dotted line beneath the column for that plot. For example, under high fertility the plot that received no irrigation used, in addition to the rainfall received, about 0.37 foot of stored water from the soil. Each of the next four plots used some stored soil water, the amount in each case being represented by the vertical distance between the dotted line and the lower end of the irrigation column. Plots 6 and 7 did not use all of the water received, but stored from 0.10 to 0.15 foot. Storage of water is indicated wherever the dotted line lies above the lower end of the irrigation column, the vertical distance between the two points indicating the depth of water stored. For the three graphs, the maximum yield was produced with total depth used of 1.85 feet under high fertility, 2.10 feet under medium fertility and 2.00 feet under low fertility. Average 1.98 feet.

*Influence of Fertility*.—The curves and table on the right side of Diagram No. 2 show the influence of soil fertility on the depth of water used to produce a given yield per acre. Five curves are shown giving the yield in comparison with the depth used where wheat followed—

- (1) Alfalfa—beets—beets
- (2) Clover
- (3) Clover—corn—oats
- (4) Peas
- (5) Alfalfa—potatoes or alfalfa—corn—oats
- (6) Grass—potatoes—grain

The highest yields per acre from a given depth of water were produced where wheat followed alfalfa—beets—beets, the lowest where wheat followed grass—potatoes—grain. These curves indicate the value of different crops and crop rotations as builders of soil fertility.

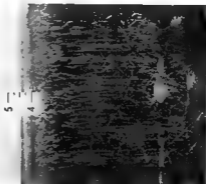
The table shows that the maximum yield per acre varied from 76 bushels under No. 1 fertility to 38 bushels under No. 6 fertility. The total depth used to produce these maximum yields varied from 1.70 feet under (1) to 2.05 feet under (6). Average total depth used to produce maximum yields, 1.84 feet. The amount used to produce a yield of 38 bushels per acre varied from 0.82 foot under (1) to 2.05 feet under (6).

*Time of Irrigation*.—A schedule giving the average time of irrigation for wheat as applied at Brooks to produce the results shown in the graphs is given in lower right of diagram. By comparing it with the graph, the irrigation treatment producing the yield of any plot may be ascertained.

## MARQUIS WHEAT



Not Irrigated



Five to six Irrigations

RELATIVE VALUE OF DIFFERENT DEPTHS PER APPLICATION

Depth applied	Yield in Bushels per acre		
	High	Medium	Low
3 x 4" = 12"	94	45	21
2 x 6" = 12"	59.5	43	20

For wheat a given quantity of water produced a higher yield per acre if applied in 4 inch irrigations than if applied in 6 inch irrigations.

**Summary.** The average total depth of water used which produced a maximum yield of wheat was 1.98 feet for the three conditions of soil fertility, high, medium and low and 1.84 feet for wheat grown in six different rotations as shown by the curves. Mean 1.91 feet or 23 inches.

### WATER REQUIREMENTS OF OATS

*Diagram No. 3* shows by column graphs the water requirements of Banner oats under three conditions of soil fertility, high, medium and low and by curves the influence of soil fertility on the depth of water used per unit of yield. In general, the explanation given for diagram No. 1 as regards rainfall, irrigation column, dotted water-use curve, etc. will apply to all diagrams.

**Total Depth Received.**—The maximum yield was produced with a total depth received of 1.83 feet in high fertility, 2.17 feet in medium fertility and 2.04 feet in low fertility. Average 2.01 feet.

**Total Depth Used.** The maximum yield was produced with a total depth used of 1.87 feet in high fertility, 1.90 feet in medium fertility and 1.80 feet in low fertility. Average 1.86 feet.

**Influence of Fertility.** The curves and table on the right side of diagram No. 3 show the influence of soil fertility on the depth of water used to produce a given yield per acre. Five curves are shown giving the yield in comparison with the depth used where Banner oats followed:—

- (1) Clover
- (2) Clover—corn
- (3) Clover—corn—oats—wheat.
- (4) Peas—wheat
- (5) Wheat

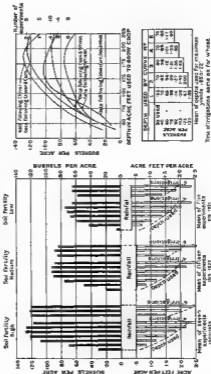
The highest yields per acre from a given depth of water were produced where oats followed clover, the lowest where oats followed wheat only. Curves 1, 2 and 3 show the crop producing power built into the soil by clover. Curves 2 and 4 may be used to compare the fertilizing value of clover and peas.

The table shows that the maximum yield per acre varied from 130 bushels under No. 1 fertility to 75 bushels under No. 5 fertility. The total depth used to produce these maximum yields varied from 1.65 to 2.00 feet. The average total depth used to produce maximum yields was 1.86 feet or 22.2 inches. The amount used to produce a yield of 75 bushels per acre varied from 0.86 foot under (1) to 1.80 feet under (5).

**The Time of Irrigations** for oats is the same as for wheat, as shown on diagram No. 2.

MINISTRY OF THE INTERIOR, CANADA  
DEPARTMENT OF AGRICULTURE AND RURAL DEVELOPMENT

# WATER REQUIREMENTS OF BANNER OATS



## RELATIVE VALUE OF 4- AND 6-INCH IRRIGATIONS

Depth applied	Yield in Bushels per acre		
	High	Medium	Low
3 x 4" = 12"	153	90	67
2 x 6" = 12"	120	65	58

For oats, a given quantity of water produced a higher yield per acre if applied in 4-inch irrigations than if applied in 6-inch irrigations.

*Summary*.—The average total depth of water used which produced the maximum yield of oats was 1.86 feet for the three conditions of soil fertility,—high, medium and low,—and 1.85 feet for oats grown in five different rotations as shown by the curves. Mean 1.855 feet or 22.2 inches.

## WATER REQUIREMENTS OF BARLEY

*Diagram No. 4* shows by column graphs the water requirements of two varieties of barley under high and medium fertility. O. A. C. No. 21 barley was used up to and including 1923. Bark's barley was used from 1924 to 1926 inclusive.

*Total Depth Received*.—For Bark's barley the maximum yield was produced with a total depth received of 1.22 feet in high fertility and 2.22 feet in medium fertility, average 1.72 feet. For O. A. C. No. 21 barley the maximum yield was produced with a total depth received of 1.88 feet in high fertility and 1.88 feet in medium fertility. The average total depth received producing maximum yields for the two barleys is 1.80 feet.

*Total Depth Used*. The maximum yield was produced with a total depth used of 1.25 feet in Bark's, high fertility, 2.10 feet in Bark's, medium fertility; 1.80 feet in O. A. C. No. 21, high fertility, and 1.80 feet in O. A. C. No. 21, medium fertility. The average depth used for the four barley graphs is 1.74 feet.

*Influence of Fertility*.—Twelve inches of water produced 80 bushels of Bark's barley per acre following clover-wheat and but 40 bushels per acre where the same barley followed grass-potatoes or peas-wheat. Twelve inches of water produced 42 bushels of O. A. C. No. 21 barley per acre following clover-oats and but 26 bushels per acre where the same barley followed grass-potatoes or peas-wheat-oats.

*Time of Irrigations* for barley is shown in the small graph in lower right of diagram No. 4.

## RELATIVE VALUE OF 4- AND 6-INCH IRRIGATIONS

Depth applied	Yield in Bushels per acre			
	Bark's Barley		O. A. C. No. 21 Barley	
	High	Medium	High	Medium
3 x 4" = 12"	67	55	57	43
2 x 6" = 12"	52	42	55	34



For barley, a given quantity of water produced a higher yield per acre if applied in 4-inch irrigations than if applied in 6-inch irrigations.

**Summary**—The average total depth of water used which produced the maximum yield of barley was 1.74 feet.

### WATER REQUIREMENTS OF FLAX

*Diagram No. 5* shows the water requirements of flax and corn. One graph is shown for flax as this crop was grown each year under the same condition of fertility in rotation "A" as indicated. A fallow five years-potatoes-wheat-flax. The maximum yield for the six experiments, 24.5 bushels per acre, was produced under a depth of water of 2.17 feet, of which 1.67 feet were received in five 4-inch irrigations, the dotted line, however, shows that a depth of only 1.70 feet was used in producing this yield, the plot storing 0.47 feet of water. This graph emphasizes the importance of the "dotted line" data, gained by soil moisture studies made in connection with the irrigation treatment of each plot. Without these data, conclusions would be drawn that a depth of 2.17 feet was necessary to produce the maximum yield of flax. With the "dotted line" data, however, the amount of water drawn from the soil or stored in the soil by each plot may be readily determined.

Yield in bushels per acre	Total depth used to grow the crop	
	With 4-inch irrigations	With 6-inch irrigations
6.0	0.45	—
12.0	0.85	—
17.5	1.1	1.50
22.0	1.55	1.77
24.5	1.70	—

It requires approximately 4 inches more water to produce a yield of 17.5 bushels per acre where applied in 6-inch than where applied in 4-inch irrigations. Flax, being a comparatively shallow rooted crop, is best watered with the lighter irrigations.

### WATER REQUIREMENTS OF CORN

The data secured from experiments on three varieties of corn are shown on diagram No. 5. The maximum yield was produced under a total depth received of 1.07 feet for Golden Bantam, 1.75 feet for North West Dent and 1.77 feet for Minnesota No. 13. Average depth received, 1.53 feet.

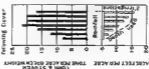
The total depth used in producing the maximum yield was 1.35 feet for Golden Bantam, 1.40 feet for North West Dent and 1.35 feet for Minnesota No. 13. Average depth used, 1.37 feet.

The time of irrigations for corn is shown at right of Diagram No. 5.

DEPARTMENT OF THE AGRICULTURE, CANADA  
 CANADIAN WATER RESOURCES AND RECLAMATION SERVICE

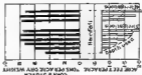
# WATER REQUIREMENTS OF CORN AND FLAX

GOLDEN BANTAM  
 following clover



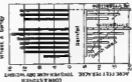
One experiment  
 rain only

NORTHWEST DENT  
 following corn



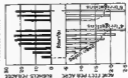
Mean of two  
 experiments (see p. 10)

MINNESOTA 1913  
 following clover  
 wheat & barley



One experiment  
 rain only

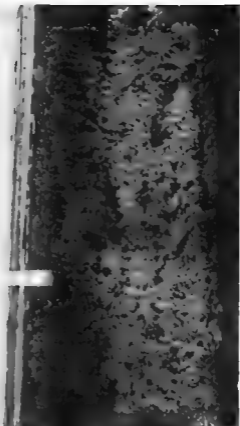
FLAX  
 following alfalfa & vipers  
 potatoes & wheat



Mean of six  
 experiments (see p. 10)



One of Minnesota 1906 flax  
 same as potatoes



## WATER REQUIREMENTS OF POTATOES

The first two graphs from the left on diagram No. 6 show the water requirements of potatoes grown under two conditions of soil fertility, following alfalfa and following mixed hay grass.

**Total Depth Received.**—The maximum yield was produced with a total depth received of 1.77 feet following alfalfa and 1.60 feet following grasses. *Average 1.68 feet.*

**Total Depth Used.**—The maximum yield was produced with a total depth used of 1.70 feet following alfalfa and 1.60 feet following grasses. *Average 1.65 feet, or 19.8 inches.*

**Influence of Fertility.**—The following table shows the depth required to produce a given yield of potatoes per acre as influenced by soil fertility and by the depth applied per irrigation.

Yield in Bushels per acre	Depth used, in inches, per acre			
	Following alfalfa		Following mixed grass	
	2-inch irrigations	3-inch irrigations	2-inch irrigations	3-inch irrigations
100	0.60		0.65	
200	0.85		1.05	.65
300	1.25	1.25	1.40	.65
335	1.33	1.33	1.45	
400	1.47	1.47		
435	1.60	1.60		
440	1.65			

For the potatoes on alfalfa land the same depth was used whether the water was applied in 2- or 3-inch irrigations. Where the potatoes followed grass the 2-inch irrigation was the more economical. A depth of 1.65 feet produced 125 bushels more per acre where the crop followed alfalfa than where it followed grass.

## WATER REQUIREMENTS OF PEAS

The third graph on *Diagram No. 6* shows the water requirements of the Prussian Blue variety of Canada field peas. The graph was plotted from the mean of nine experiments from 1918 to 1925, inclusive. The maximum yield, 46 bushels per acre, was produced under a depth of water of 1.83 feet, of which 1.33 feet were received in 4-inch irrigations. The total depth used to produce the maximum yield was 2.06 feet. In every plot of this crop series, except that receiving four 6-inch irrigations more water was used to grow the crop than was received.

Yield in bushels per acre	Total depth used to grow the crop	
	With 4-in. irrigations	With 6-in. irrigations
10	0.75	0.70
20	0.97	0.97
32	1.35	1.68
45	.97	2.11
46	2.06	

For peas the 4-inch irrigation was the most economical.

DEPARTMENT OF THE ARMY, CANADA  
SOUTHERN WATER POWER AND IRRIGATION DISTRICT

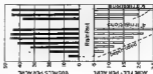
# WATER REQUIREMENTS OF POTATOES, PEAS AND GRASSES

POTATOES— GOLD COIN & NETTED GEM  
(1900 - 1902)



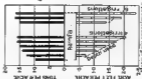
Mean of five experiments 1901-1902 inclusive

PRUSSIAN BLUE PEAS



Mean of nine experiments  
1900-1902 inclusive

MIXED HAY  
GRASSES

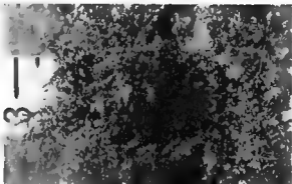


Mean of six experiments  
1900-1902 inclusive

TIME OF IRRIGATION FOR PEAS  
GRASSES SAME AS FOR WHEAT

TIME OF IRRIGATION FOR POTATOES		
JULY	AUG.	SEP.
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9
10	10	10
11	11	11
12	12	12

## GRIND ALP ALFA (From the Road)



Three 3" in picture



New lot (not)

## WATER REQUIREMENTS OF MIXED GRASS

Brake grass, Western Ryegrass, Meadow Fescue, Meadow Foxtail, Timothy and Alsike clover were seeded in a mixture for hay. The fourth graph on diagram No. 6 shows the results obtained. The maximum yield 1.66 tons per acre was produced under a total depth of water received of 1.90 feet. The total depth used to produce the maximum yield was 1.63 feet.

## WATER REQUIREMENTS OF GRIMM ALFALFA

Diagram No. 7 shows by column graphs the water requirements of *Ononis alfalfa* from two to five years old and by three curves and a table at the right of the diagram the depth of water used per ton of hay produced for alfalfa two years, three years and four to five years old.

*Influence of Age of Plant.* The yield in tons per acre for any given depth of water increases with the increasing age of the alfalfa except on those plots which either receive too little or too much water. After the third year the yield from the plots that do not receive enough water decreases, due to a thinning out of the stand from winter killing and to a retarded root development due to insufficient water. Between a depth used of 1.85 and 2.15 feet one curve is traveled from alfalfa plots four and five years old is up to one ton per acre greater than the yield from a alfalfa plot three years old. Where the depth used was in excess of 2.15 feet or less than 1.85 feet the yield of the four and five year old alfalfa was up to 1½ tons per acre less than the three year old alfalfa. Where sufficient water is applied to maintain the soil moisture near the optimum content the root system will continue to develop and extend outwardly and downward through the soil. As the soil volume occupied by the plant roots increases so does the plants food and water resources storage. The depth of water required to produce a yield of 5.6 tons of alfalfa per acre varied from 2.02 feet where the plant was four or five years old to 2.20 feet where the plant was two years old. The root occupied volume of a normal plant four years old is much greater than that of a plant two years old. There is a larger proportion of each applied irrigation is retained within reach of the roots of the older plant than is retained in the root occupied zone of the younger one. The depth used is therefore decreased by the amount used or lost by percolation below the root zone. The older plant even with its larger root zone has access to more plant food than the younger one.

*Total Depth Received.* The maximum yield was produced with a total depth received of 2.50 feet in the two year old, 2.22 feet in the three year old and 2.02 feet in the four and five year old series. Average 2.25 feet.

*Total Depth Used.* The maximum yield was produced with a total depth used of 2.15 feet in the two year old, 2.10 feet in the three year old and 2.22 feet in the four and five year old series. Average 2.02 feet or 26.4 inches.

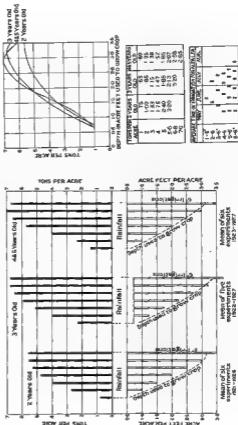
The average time of irrigations for alfalfa is shown at the bottom right of diagram No. 7. Six inch irrigations have proven the most economical for alfalfa.

## WATER REQUIREMENTS OF SUGAR BEETS

Diagram No. 8 shows by three column graphs the water requirements of sugar beets under high, medium and low conditions of soil fertility and by curves the depth of water used per ton of crop produced where beets were grown first and second years after beta alfalfa and clover. The dotted line over beet columns shows yield of sugar in pounds per acre.

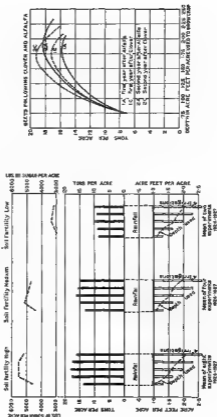
DEPARTMENT OF THE INTERIOR, CANADA  
 IRRIGATION WATER POWER AND RECLAMATION SERVICE

# WATER REQUIREMENTS OF GRIMM ALFALFA



COMPARISON OF THE INTENSIVE, CANADA  
COMMON WATER POWER AND ESTABLISHMENT METHOD

# WATER REQUIREMENTS OF SUGAR BEETS



**Total Depth Received** The maximum yield was produced with a total depth received of 1.97 feet in high fertility, 1.97 feet in medium fertility and 1.97 feet in low fertility. Average 1.97 feet.

**Total Depth Used** The maximum yield was produced with a total depth used of 1.58 feet in high fertility, 1.55 feet in medium fertility and 1.58 feet in low fertility. Average 1.60 feet.

All beet plots show water stored in the soil at the end of the season. This varies in amount from three to ten inches. See dotted line under beet column graphs on Diagram No. 8. This is due principally to heavy rains in the fall, after the scheduled irrigations had been applied.

**Influence of Fertility** A comparison of curves 1A and 2A shows that sugar beets grown as second crop after alfalfa produced approximately two tons per acre more than when grown immediately following alfalfa, so that when grown as the second crop after clover (2C) sugar beets produced approximately two tons more per acre than when grown immediately following clover. The plant foods introduced into a soil by the ploughing under of a leguminous crop become available to succeeding crops only as they are converted into soluble plant foods by bacteria action. Aeration of the soil through cultivation, moisture and warmth are necessary to the bacteria for breaking down the organic residue of the leguminous crop and converting it into soluble plant foods. A comparison of curves 1A and 1C shows that beets grown the first year after clover (1C) produced approximately 1½ tons per acre more than when grown first year after alfalfa (1A). A comparison of curves 2A and 2C shows that beets grown as the second crop after clover produced nearly 1½ tons more per acre than when grown as the second crop after alfalfa. The residue from clover—roots, leaves and stems—is converted into available plant food quicker than that from alfalfa. Eighteen inches of water produced a yield of 18.0 tons of beets per acre under high fertility and but 10.5 tons per acre under low fertility—a difference in yield of 7.5 tons per acre, due to soil fertility.

The time of irrigation for sugar beets and the amount of water used per month or through the different stages of their growth is shown on diagram No. 1.

#### WATER REQUIREMENTS OF ALFALFA GROWN FOR SEED, 1919 TO 1921, INCLUSIVE

The following graph shows results obtained with seed alfalfa. The crop series area was divided into five plots—plot No. 1 was non-irrigated, the other four plots received from one to four irrigations of 3 inches depth.

Each plot was divided into three equal parts—on the first of which the alfalfa was sown in drills 7 inches apart, on the second in rows 28 inches apart and on the third in hills 36 inches apart each way.

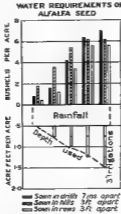
Where seeded in drills the maximum yield, 7 bushels per acre, was obtained from plot No. 5 under a depth of water of 1.50 feet.

Where seeded in hills, the maximum yield, 6.2 bushels per acre, was obtained from plot No. 4 under a depth of water of 1.25 feet.

Where seeded in rows the maximum yield, 5.8 bushels per acre, was obtained from Plot No. 5, under a depth of water of 1.50 feet. The dotted curve showing the depth used to grow the crop agrees very closely with the depth received.

It will be noted that up to the point where two irrigations were applied, the maximum yield was produced by the hill seeding, as more water was applied the drill seeding produced the greater yield.

The data here presented cover but three seasons' investigations and while valuable as indicating the water requirements of seed alfalfa are not conclusive.



Laying out Small Plots for Alfalfa Seed Tests

## SUMMARY OF INVESTIGATIONS AT THE BROOKS STATION

The accompanying table gives in acre feet, the mean depth of water used which produced the maximum crop yields per acre under different conditions of soil fertility.

No. of Experiments.	Crops	Soil fertility			Mean depth used		Economic depth per acre (inches in surface)
		High	Medium	Low	Feet	Inches	
17	Alfalfa	2.03			2.03	24.4	0
9	Pean	2.05			2.05	24.6	0
20	Wheat	1.45	2.10	2.00	1.46	22.6	4
20	Oats	1.07	1.90	1.00	1.06	22.3	4
17	Barley—Barke.	1.03	2.10				
	O & C 21	1.06	1.00		1.24	20.9	4
4	Flax	1.70			1.70	20.4	4
4	Potatoes.	1.70	1.00		1.00	19.3	3
4	Grass.		1.03		1.03	19.3	3
14	Beets	1.00	1.03	1.00	1.00	19.2	4
3	Alfalfa seed	1.45			1.45	17.6	3
4	Corn.	1.27			1.27	16.4	3

## DUTY OF WATER INVESTIGATIONS AT RONALD, ALBERTA

Investigations were commenced in 1914 at Ronald in co-operation with the Canada Land & Irrigation Company, a tract of forty acres, owned by that company. This tract was chosen partly because of the exceptional facilities offered by the company for experimental work, partly because it is situated in the centre of an area of progressive irrigation development, but chiefly because of the fact that the soil and water conditions are of a type meeting to which it was very probable that duty of water tests should be conducted.



Sugar Beets following Alfalfa. Plot 66, 1917

**Depth of Soil** The soil is somewhat lighter than at Brooks, washes easier and contains a higher percentage of fine sand. The soil of the main test plot area is only two to three feet deep and is underlain by a stratum of coarse gravel. In consequence, the water-holding capacity of this soil is relatively low as will be found by reference to the accompanying diagram and table. At Ronalane a given yield of grain per acre used much more water to grow the crop than at Brooks where the soil is deep. This is due principally to the greater percentage of each irrigation which is lost to the crop by percolation below the three-foot depth of soil.

**Fertility** A. the plots at Ronalane except those growing alfalfa received frequent heavy applications of manure and the crops produced may therefore be considered as obtained under optimum conditions of soil fertility.

**Depth of Irrigations**—Four inch irrigations were used on the grain and pea crops and three inch irrigations on the potato crops. The alfalfa plots were the only ones given six-inch irrigations, and were situated some distance north of the other plots on soil about six feet deep.

The accompanying diagram shows the average results obtained with six different crops, covering a period of four years, 1917 to 1921, inclusive.

#### WATER REQUIREMENTS

**Canada Blue Peas**—The maximum yield of peas, 43.5 bushels per acre, was obtained with a depth of water of 2.37 feet, of which 2.00 feet were applied in six 4-inch irrigations. The depth used to produce the maximum yield was 2.37 feet. The field peas at Ronalane were subject to attacks of mildew hence their low yields as compared with the yields obtained at Brooks.

**Marquis Wheat**—The maximum yield of wheat, 46 bushels per acre, was obtained with a depth of water of 2.02 feet of which 1.67 feet (or 20 inches) were applied in five 4-inch irrigations. The depth used to produce the maximum yield was 2.20 feet.

**Abundance Oats** The maximum yield of oats, 81 bushels per acre, was obtained with a depth of water of 1.70 feet, of which 1.33 feet (16 inches) were applied in four 4-inch irrigations. The depth used to produce the maximum yield was 1.82 feet.

**Bark's Barley** The maximum yield of barley, 53 bushels per acre, was obtained with a depth of water of 1.70 feet, of which 1.33 feet (16 inches) were applied in four 4-inch irrigations. The depth used to produce the maximum yield was 1.75 feet.

**Grimm Alfalfa**—The maximum yield of alfalfa, 3.25 tons per acre, was obtained with a depth of water of 2.40 feet, of which 2.00 feet were applied in six 4-inch irrigations. As the amount applied was increased beyond this point the yield diminished.

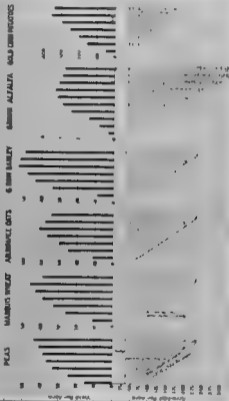
**Gold Coin Potatoes**—The maximum yield of potatoes, 355 bushels per acre, was obtained with a depth of water of 1.65 feet, of which 1.25 feet were applied in five 3-inch irrigations.

#### SUMMARY

The following table shows average depths of water for maximum yields at Ronalane—

Crop	Depth received	Depth used	Yield per acre
Peas	2.37 feet	2.37 feet	43.50 bush.
Wheat	2.02 "	2.20 "	46.00 "
Oats	1.70 "	1.82 "	81.00 "
Barley	1.70 "	1.75 "	53.00 "
Alfalfa	2.40 "		3.25 tons
Potatoes	1.65 "		355.00 bush.

ROMALANE EXPERIMENT STATION  
 GROUND WATER TABLE - 1940-1941



When comparing this table with the results obtained at Brooks, all Rosalane results are considered as coming under the heading of No. 1 fertility due to the frequent applications of manure.

The principal factor responsible for so much water being required to produce the maximum yield per acre at Rosalane is the shallow depth of soil and consequent high percolation loss through the underlying stratum of gravel.

#### DUTY OF WATER INVESTIGATIONS AT COALDALE, ALBERTA, 1913 TO 1921

A necessary part of investigations for the determination of a practical duty of water is the carrying on of experimental work under ordinary field conditions in accordance with methods that can be used by the average farmer. Work of this character has been conducted since 1913 on a number of farms in the Coal-dale district. Surveyed tracts, varying in size from five to fifty acres, were set aside by the farmers. Irrigation specialists planned the layout of the ditches on these tracts, measured the water applied and generally assisted the farmers in the irrigation of their crops. In the course of this work the farmers were made acquainted with the best practical methods of irrigating their lands and, at the same time, valuable information was obtained by the department regarding the results following the application of water under field conditions. This information is a very useful supplement to the data collected at the experimental stations where the work is necessarily confined to small test plots.

In selecting the tracts at Coal-dale the following requirements were kept in mind:—

1. The location and size of the tract should be such that the water applied to any adjacent field would have no influence upon the crop grown on the tract under investigation.

2. The general topography of the tract should be such as would permit of the accurate measurement of the water supplied to and wasted from the tract.

3. The tract should be as near Coal-dale as possible so as to permit of one engineer looking after several farms.

Gauges, sills, weirs and rating flumes were installed for the measurement of the supply and waste water. Each measuring device was equipped during the period of each irrigation with an automatic water-stage register in order to obtain a continuous gauge height record.

The acreage and area of each field were measured by the engineer.

As most of the farms selected had telephones the engineer had little difficulty in ascertaining the exact date upon which a farmer would commence irrigating and he could therefore place the gauges in time to record the first flow of water.

Temperature, evaporation and precipitation records were kept from April 1 to September 30 in each year. Soil moisture tests were made on each tract at the beginning and end of each season's growth. By these tests the moisture content of the soil was determined to a depth of six feet.

Table No. 1 shows the average total depth of water received (irrigation plus precipitation) by the Coal-dale tracts 1913-21 inclusive. The average total depth received by the grain crops is 1.51 feet, the average duty of water for grains is 0.60 foot. For alfalfa and grasses the average total depth received is 2.00 feet, the average duty for forage crops is 1.22 feet. For all tracts under observation, alfalfa, grass and grains the average total depth received is 1.95 feet, the average duty for all these crops is 1.16 feet. Of the 140 individual observations which go to make up the average duty of 1.16 feet, 81 are on alfalfa, 26 on wheat, 15 on oats, 12 on timothy and 6 on barley, 38 per cent grain crops and 62 per cent forage crops.

TABLE No. 1. SEQUENCING DEPTH OF WATER USED ON CALDALE TRACTS 19.3 TO 601

Crop	1913				1914				1915				1916				1917			
	Depth of water applied	Precipitation	Total depth measured	Depth of water applied	1914		Depth of water applied	Precipitation	Total depth measured	Depth of water applied	Precipitation	Total depth measured	Depth of water applied	Precipitation	Total depth measured	Depth of water applied	Precipitation	Total depth measured	Depth of water applied	Total depth measured
					Depth of water applied	Precipitation														
Crop	1.15	0.00	1.15	0.00	1.46	0.57	1.46	0.57	3.41	1.32	1.32	1.32	0.50	1.56	1.36	.50	0.45	1.40	1.40	1.40
	0.00	0.00	0.00	0.00	1.52	0.57	1.52	0.57	1.52	0.57	0.57	0.57	0.50	0.50	1.07	0.49	0.41	0.90	0.90	0.90
	0.00	0.00	0.00	0.00	1.46	0.57	1.46	0.57	1.46	0.57	0.57	0.57	0.50	0.50	1.07	0.49	0.41	0.90	0.90	0.90
	0.00	0.00	0.00	0.00	1.46	0.57	1.46	0.57	1.46	0.57	0.57	0.57	0.50	0.50	1.07	0.49	0.41	0.90	0.90	0.90
	0.00	0.00	0.00	0.00	1.46	0.57	1.46	0.57	1.46	0.57	0.57	0.57	0.50	0.50	1.07	0.49	0.41	0.90	0.90	0.90
Average for all tracts.																				
Crop	1.70	0.30	1.00	1.00	1.33	0.63	1.73	0.63	1.10	1.11	0.41	1.52	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
Average for all tracts.																				
Crop	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
Average for all tracts.																				
Crop	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
Average for all tracts.																				
Crop	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
	1.00	0.30	0.70	0.70	1.33	0.63	1.96	0.63	1.33	0.63	0.63	1.33	1.33	0.43	1.76	1.33	0.79	1.00	1.00	1.00
Average for all tracts.																				

TABLE No. 3—WATER USED BY ALFALFA AND TIMOTHY TRACTS EACH YEAR 1913 TO 1921, COALDALE, ALBERTA.

Plot No.	Year	Crop	Depth of water applied	Precipitation	Total depth received	Yield per acre	
203	1913	Alfalfa	1.71	0.98	2.69	4.70	Flooded by waste water.
	1914		1.39	0.87	2.26	4.31	
	1915		0.48	1.32	1.80	3.80	
	1916		1.83	1.76	3.59	5.31	
	1917			0.75		3.08	
	1918		3.45	0.31	3.76	2.72	
	1919		1.75	0.84	2.59	4.11	
	1920		0.84	0.51	1.35	2.45	
	1921		0.97	0.44	1.41	2.13	
Average					2.19	3.20	
204	1913	Alfalfa	1.79	0.98	2.77	4.49	Irrigation too late. Second irrigation too late.
	1914		1.79	0.57	2.37	4.97	
	1915		1.02	1.32	2.34	4.94	
	1916		0.00	1.59	1.59	3.18	
	1917		0.78	0.70	1.48	2.45	
	1918		1.75	0.30	2.05	2.85	
	1919		1.68	0.45	2.13	4.05	
	1920		1.41	0.79	2.20	4.39	
	1921		1.44	0.45	1.89	3.34	
Average					2.51	3.77	
206	1914	Alfalfa	1.00	0.57	1.57	3.09	Seeded. One irrigation too heavy.
	1915		0.39	1.32	1.71	3.19	
	1916		0.78	1.59	2.37	3.13	
	1917		1.48	0.70	2.18	2.65	
	1918		1.89	0.27	2.16	3.38	
	1919		1.16	0.40	1.56	4.24	
	1920		1.36	0.31	1.67	4.00	
	1921		1.44	0.45	1.89	4.00	
Average					2.05	3.49	
210	1914	Alfalfa	1.45	0.57	2.02	3.44	Seeded. No water for irrigation. Poor irrigation.
	1915		0.39	1.32	1.71	1.94	
	1916		0.00	1.59	1.59	2.48	
	1917		0.00	0.72	0.72	1.48	
	1918		1.35	0.30	1.65	3.05	
	1919		1.64	0.40	2.04	4.05	
	1920		1.21	0.35	1.56	3.95	
	1921		1.38	0.45	1.83	2.45	
Average					1.47	2.67	
212	1914	Alfalfa	3.41	0.51	3.92	3.18	Seeded.
	1915		0.84	1.32	2.16	1.91	
	1916		0.00	1.59	1.59	1.91	
	1917		1.79	0.60	2.39	2.24	
	1918		1.22	0.30	1.52	3.09	
	1919		1.57	0.40	1.97	4.37	
	1920		1.38	0.31	1.69	3.43	
	1921		1.44	0.45	1.89	2.94	
Average					2.13	2.94	
213	1914	Alfalfa	1.81	0.57	2.38	3.48	Seeded. No record in 1915. Two light irrigations.
	1915						
	1916		0.00	1.59	1.59	3.48	
	1917		1.43	0.60	2.03	4.15	
	1918		3.28	0.35	3.63	3.48	
	1919		1.85	0.40	2.25	4.84	
	1920		1.15	0.30	1.45	4.56	
Average					2.30		

TABLE No. 2. WATER USED BY ALFALFA TRACTS AND TIMOTHY EACH YEAR 1913 TO 1921 GOALDALE ALBERTA—(continued)

Plot No.	Year	Crop	Depth of water applied	Precipitation	Total depth received	Yield per acre	
Average					2.07	2.32	
314	1914	Alfalfa	1.31	0.57	2.48		Seeded.
	1915		1.43	1.25	1.43	2.45	
	1916		0.60	1.54	1.54	2.45	
	1917		0.65	0.73	0.73	2.34	Not irrigated
	1918		2.31	0.33	2.64	4.22	
	1919		2.45	0.65	2.64	3.23	
	1920		2.21	0.83	2.64	4.56	
	1921		1.74	0.48	1.66	2.45	
Average					2.12	3.23	
315	1914	Alfalfa	2.33	0.57	2.50		Seeded
	1915		0.20	1.25	1.52	2.44	
	1916		0.60	1.54	1.54	2.45	
	1917		1.01	0.66	1.66	2.36	
	1918		2.41	0.34	2.15	4.27	
	1919		2.60	0.43	2.45	3.43	
	1920		1.64	0.81	2.45	3.75	
	1921		2.12	0.45	2.50	2.36	
Average					2.27	3.20	
321	1918	Alfalfa	2.06	0.30	2.55	3.31	
	1919		1.74	0.46	2.29	4.42	
	1920		.73	0.45	2.34	5.47	
	1921		1.51	0.41	1.96	2.33	
Average					2.28	4.25	
322	1918	Alfalfa	1.40	0.44	.40	2.45	
	1920		0.64	0.45	.45	2.55	Flooded by waste water
	1921		2.05	0.45	2.45	2.72	Under irrigation.
Average					1.83	2.73	
324	1919	Alfalfa.	1.25	0.44	.71	3.7	
	1920		0.73	0.79	.50	2.79	
	1921		1.56	0.52	2.45	2.25	
Average					.60	2.92	
325	1914	Alfalfa and Timothy	2.56	0.37	2.55	2.76	
	1915		0.00	1.32	1.32	4.16	
	1916		1.05	1.55	2.65	2.83	
	1917		1.55	0.70	2.05	2.83	
	1918		2.33	0.50	2.83	4.74	
	1919		1.45	0.48	1.92	5.17	
	1920		1.66	0.81	2.07	4.55	
	1921		1.74	0.45	2.19	4.25	
Average					2.40	4.0	
326	1914	Timothy	0.24	0.57	2.95		Seeded
	1915		1.43	1.25	2.73	1.50	
	1916		0.37	1.55	1.55	1.40	
	1917		1.49	0.71	0.71	1.33	
	1918		1.05	0.33	1.49	0.33	Not sown and pastured
	1919		1.35	0.33	1.50	0.43	
	1920		0.80	0.75	1.54	1.74	
	1921		0.35	0.38	0.71	1.03	
Average					1.99	1.03	

Table No. 2 gives a history of each of the thirteen fields under forage crops. The average yield in tons per acre during the period of years for which records are available on each field will be found to vary from 2.64 tons on field 312 to 4.28 tons on field 324. This variation in yield is due to the difference in the stand of crop, the skill of the irrigator and the type of soil. The average yield of 4.28 tons per acre from field 324 was produced with an average depth of water of 2.26 feet, only 0.13 foot more water than was used in field 312.

Results of investigations at the Brooks Experiment Station have indicated that the best depth per irrigation for alfalfa is about six inches and that with this depth per irrigation a yield of  $3\frac{1}{2}$  tons of alfalfa per acre used a total depth of approximately 1.70 feet of water. The average yield of the Coaldale alfalfa tracts from 1913 to 1921 is nearly  $3\frac{1}{2}$  tons per acre, but the total depth of water used in producing this yield was 2.22 feet applied in irrigations of an average depth of about 9 inches. Therefore, the Coaldale tracts have used approximately 58 per cent more water than the Brooks plots to produce a given yield. If 6 inches is the economical depth per irrigation the Coaldale farmers in applying 9 inches per irrigation are losing 3 inches or 38 $\frac{1}{2}$  per cent of each irrigation by deep percolation. It is not to be expected that the general field use of water will ever be quite as economical as that of the Experiment station, but wastage can be greatly reduced by applying the water in lighter and more frequent irrigations.

TABLE No. 3—SHOWING AVERAGE IRRIGATING HEAD USED AND ACREAGE IRRIGATED (PER 24 HOURS), COALDALE, ALBERTA, 1921

Crop	Average depth applied per irrigation	Acres irrigated per 24 hours	Average irrigating head used	
	Ft		Ft	
Alfalfa	0-33	4.30	1.65	
Timothy	0-34	2.68	0.84	
Grains	0-47	5.22	1.47	
Average all tracts, 1921	0-75	4.38	1.22	
Average for all tracts.	1920	0-68	5.48	2.10
	1919	0-75	4.25	1.81
	1918	0-66	4.42	2.35
	1917	1.15	4.03	2.58
	1916	0-74	6.24	2.45
	1915	0-68	5.30	2.11
	1914	0-66	4.02	2.27
	1913	0-72	5.06	2.22
Average, 1913 to 1921	0-81	5-01	2-22	

Table No. 3 shows the average depth of water applied per irrigation, the irrigating head used, and the acreage irrigated per 24 hours for all tracts under observation during the period 1913-21.

The farmers have irrigated 5.01 acres per day with a head of 2.22 feet, applying 9.7 inches (0.81 foot) per irrigation.

Theoretically, an irrigating head of 2.22 second-feet will deliver 53 acre-inches in 24 hours. At this rate, if applied in six-inch irrigations, this amount should cover approximately nine acres, but instead of covering this area the farmers have only been covering five acres per day. They have been losing too large a percentage of their irrigation water by percolation and surface waste. The surface waste loss may be lessened by more careful levelling of the land and

better supervision of the irrigations. The percolation waste may be decreased by applying the water in lighter irrigations. Many irrigators overrate the water-holding capacity of the soil and the power of capillarity to return appreciable quantities of water to the root zone.

With a better general understanding of the water-holding capacities of soils as outlined under Section 3 of this bulletin, irrigation farmers should be able to save much of the water now lost by percolation and to raise the average area irrigated per day, from five towards the possible nine acres.

TABLE No. 4.—EVAPORATION IN INCHES FROM A FREE WATER SURFACE, COALDALE, ALBERTA 1915 TO 1921

	1915	1916	1917	1918	1919	1920	1921	Average 1915 to 1921
April	5.48	1.81	3.65	3.20	6.58	3.11	2.05	3.60
May	4.28	5.12	4.83	4.79	5.30	6.68	3.69	5.26
June	2.56	4.66	6.78	7.66	7.30	6.47	6.63	6.86
July	4.38	6.20	9.30	7.94	8.33	6.92	6.53	7.61
August	4.87	4.70	5.53	8.79	5.91	5.73	6.06	6.78
September	2.83	3.69	4.35	3.76	3.81	4.80	4.38	3.84
Totals	24.50	35.80	38.94	38.97	37.33	32.54	29.23	30.73

TABLE No. 5.—MEAN MONTHLY TEMPERATURES AND PRECIPITATION 1913-21, INCLUSIVE COALDALE, ALBERTA

	1913		1914		1915		1916		1917	
	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
April	43.8	0.22	42.4	0.34	50.0	0.00	44.2	0.28	38.3	0.79
May	48.4	1.76	51.7	0.88	51.1	3.09	48.6	4.12	48.7	0.68
June	64.0	4.76	58.6	1.67	54.7	3.31	58.4	3.83	56.4	2.11
July	69.4	1.28	67.0	0.69	59.3	5.35	63.3	3.47	64.5	0.38
August	63.4	1.93	62.3	2.58	67.3	6.38	60.4	3.25	63.3	1.56
September	54.6	1.55	53.5	1.05	50.4	3.11	52.6	4.79	55.1	2.03
Average temperature and total precipitation	56.5	11.79	55.9	6.34	55.4	14.84	54.5	18.71	55.4	8.66

	1918		1919		1920		1921		Average 1913-1921	
	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
April	42.8	0.35	43.4	0.63	31.1	3.54	41.2	0.54	42.3	0.73
May	44.6	1.03	49.9	1.88	47.8	1.66	51.0	1.26	49.0	1.73
June	63.0	0.45	56.3	0.66	57.0	1.00	60.8	2.66	58.7	2.32
July	64.3	0.25	65.4	1.27	60.0	3.21	64.9	2.17	64.3	1.34
August	60.5	1.25	60.7	1.30	64.1	0.29	62.7	0.65	64.3	1.42
September	57.4	0.45	54.5	2.14	55.4	0.31	56.4	1.21	54.9	1.63
Average temperature and total precipitation	56.8	4.40	56.7	7.66	54.7	10.03	55.4	6.61	55.3	10.06

TABLE No. 6

Year	Plot Nos.											
	303	304	305	310	312	313	314	315	324	329	334	335
1903	4-70	4-40										
1904	4-21	4-07										3-78
1905	3-94	4-34	3-09	1-54	1-91		3-89	3-04				4-16
1906	2-91	3-14	3-16	2-46	1-57	2-46	2-89	2-93				2-63
1907	3-00	3-46	3-65	1-46	3-34	4-17	2-51	2-30				2-53
1908	3-73	2-03	3-79	3-99	3-36	3-48	4-37	4-37	3-31			4-94
1909	4-11	4-08	4-24	4-32	4-17	4-08	3-99	3-53	4-03	2-49	3-71	3-17
1910	3-66	4-39	4-03	3-93	3-43	4-53	4-06	3-73	3-18	2-97	3-79	4-78
1911	3-13	3-04	4-00	2-83	3-19		3-83	3-38	3-63	3-72	3-29	4-39
Total	30-34	30-66	34-51	30-08	18-31	19-46	34-85	32-43	17-3	9-38	9-79	33-21
Average	3-38	3-73	3-50	3-37	2-44	2-60	3-53	3-30	4-36	2-75	3-60	4-03

Table No. 6 gives a general summary of the yields in tons per acre from the Coaldale alfalfa fields. Plot 324 has produced the highest yields for the last four years, averaging 4.38 tons per acre. This tract received an average depth of 2.26 feet of water. For all fields the average yield over the entire period is 3.38 tons.

The following table shows the average yields and depths of water received for the tracts at Coaldale and the average yields and depths used for the plots at Ronalane and Brooks.

Crops	Coaldale		Ronalane		Brooks	
	Average yield	Average depth received	Average maximum yield	Average total depth used	Average maximum yield	Average total depth used
	tons	feet	tons	feet	tons	feet
Alfalfa	1.38	2-23	3-35 bush.	3-40	6-47 bush.	3-53
Pean.			43-5	3-37	46-0	3-36
Wheat		1-54	46-0	3-30	34-0	1-58
Barley		1-36	58-0	1-35	66-0	1-74
Oats		1-56	81-0	1-32	69-0	1-56
Grass hay					1-66 bush.	1-63
Alfalfa seed					7-5	1-42
Potatoes			255	1-65	27-39	1-45
Corn					23-5	1-37
Flax					34-5	1-70

The above table gives a comparison of the summaries of the Coaldale, Ronalane and Brooks investigations. The Coaldale data are from large fields, the Ronalane and Brooks data from experimental plots.

## SUMMARIES

**Coaldale.**—The figures shown for Coaldale represent the average depth of water applied by the farmers to four different crops under ordinary field conditions. They are valuable as indicating what the duty of water may be expected to be under field conditions in a project similarly situated when surface and

percolation losses are taken into consideration. The Coaldale data show that the average farmer applies an excessive depth per irrigation and allows too much water to escape by percolation and surface waste into the canals and local drainage. Lighter and more frequent irrigations would have prevented most of this waste.

*Ronalane*.—The figures shown for Ronalane represent the total depths of water used to grow the crops on a rather shallow soil, two to four feet deep, on which manure, rather than leguminous crops, has been used to maintain the fertility of the soil.

*Brooks*.—The figures shown for Brooks represent the average total depth used to produce maximum yields of crops grown under varying conditions of soil fertility. These figures indicate the amounts of water needed to produce maximum yields under what are considered to be nearly ideal irrigation conditions, where the correct amount of water is applied in irrigations of proper depth and frequency. They are applicable to districts having soil and climatic conditions similar to those at the Brooks station.

The depths used at Ronalane are considerably greater than for similar crops at Brooks, because of the smaller water-holding capacity of the Ronalane soil and a consequent greater proportional loss by deep percolation of the water applied.

The depths at Coaldale are considerably greater than at Brooks due to the large amounts of water lost by excessive depths per irrigation and surface waste.

The figures for any crop at the three places should not be averaged for the reason that the figures for grains at Brooks and Ronalane represent the total depths used in producing maximum crop yields under two entirely different conditions of soil and that the figures for grains at Coaldale represent only what was received by the crop, being usually an insufficient amount and producing only fair yields.

## SECTION 3

## WATER HOLDING CAPACITY OF SOILS

The farmer will learn to know when his crops need water by the general appearance of the plants and by an examination of the soil. It would be quite impossible for him to apply the elaborate methods of soil moisture determination which are described in the following pages. These methods are only applicable to experimental stations. In view, however, of the keen interest that has been displayed by irrigators in the subject of the water-holding capacity of soils, and of the commanding importance of this subject in any thorough study of the factors affecting the duty of water, this section has been added to the bulletin.

**Water in the Soil.** Water is found in the soil in three conditions, hygroscopic, capillary and gravitational.

**Hygroscopic Water.** Soils are finally dried so as to deprive them of all their moisture, when exposed to a moist atmosphere will absorb a certain amount of water vapour, the amount depending upon their texture (i.e. proportion of sand, silt and clay), upon their colloidal content (i.e. proportion of humus, ferrous hydrate, clay and lime), and upon their temperature. In general, sandy soils will absorb less than clay soils, and soils poor in humus less than soils rich in humus. The finer the soil texture the larger the amount of water vapour absorbed. The sandy soil at St. Paul, more absorbed about two per cent, the clay loam soil at Columbia about six and a half per cent. This moisture, which is known as hygroscopic water, is regarded as having a beneficial action in bringing into solution some of the plant food materials held in the soil on account of its close contact with the soil particles, but investigators (studying the problem from both the laboratory and field points of view) have reached the conclusion that plants are not able to use this moisture for growth.

**Capillary Water.** Capillary water is that part of the soil water which is held or moves in the soil against gravity by surface tension, the same force that causes kerosene to move along a lamp wick or ink to enter a blotter. This water adheres to the soil particles in more or less thickened films and moves freely through the soil in any direction as influenced by the two forces, gravity and surface tension. As some portion of the soil becomes drier due to the evaporation of water from the soil surface or to the absorption of water by the roots and/or plants, the film of water surrounding the soil particles at that point becomes thinner and exerts a stronger force, just as the rubber on a rubber band becomes thinner and exerts a stronger pull when stretched, draws some water from the surrounding soil particles where the film is thicker and of lower concentration. The film surrounding these drier particles in turn draws from the more moist particles adjacent and so on, moving the water from the moist to the drier portions of the soil. If the absorption or use of water at any point in the soil ceases, the capillary mechanism towards that point will cease as soon as its surrounding soil particles have received sufficient water so that the films covering them no longer exert a stronger pull than the films surrounding the other soil particles.

When water is applied to the bottom of a column of dry soil it will be observed to rise through the soil, the extent and rapidity of this rise depending upon the soil texture. Water will rise faster but to a less height in a coarse sand than in a fine sand.

From the standpoint of crop production the farmer is interested almost wholly with the water that is held by capillarity within the zone occupied by

plant roots. The movement of water through soils by capillarity is so slow as to be of relatively little value in raising sufficient quantities of water from sub-root zone regions to supply the needs of crops during the season of greatest daily use. Grain on the Strathmore plots, where the soil is a light sandy loam, suffered severely during periods of drouth, even though there was standing water at a depth of 8 feet. The grain roots, penetrating to depths of three to four feet, had depleted the moisture content of that depth to the wilting point and still the amount of water raised through the sand from the six-foot depth by capilarity was insufficient to supply the needs of the plants.

Studies made on several fields near Gleichen Alberta during the summer of 1915, showed an exhaustion of the soil moisture to a depth of three feet, beyond which the soil moisture content rapidly increased.

**Gravitational Water** As a soil becomes more and more nearly filled with water a point is reached, known as the maximum water holding capacity, where the force of gravity exerts a stronger pull than the surface tension of the water films around the soil grains. Water then begins to move downward into the soil until it either reaches the water table below or a point where the forces of gravity and surface tension are in equilibrium. This downward movement of gravitational water is commonly referred to as percolation.

## KNOWLEDGE OF WATER-HOLDING CAPACITY IMPORTANT

It is of the utmost importance that the water user should have a knowledge of the water-holding capacity of the different soil types common to his land. In order that he may intelligently plan his irrigation program he needs to know how much water can be stored in each class of soil for the use of crops, and how much can be economically applied per irrigation.

Some of the light sandy soils experimented with would retain only about one inch of available water per foot in depth, while some of the salt loam soils retained as high as three times this amount.

When irrigations are applied to a depth in excess of the water-holding capacity of any soil there is a loss due to deep percolation. This loss is harmful in that it tends to raise the general level of the ground water, leaches out soluble plant foods and causes waterlogging and a salt saturation of lands in the lower lying portions of the district.

Soil studies dealing especially with water-holding capacity, have been carried on by this department since 1914, covering many of the soil types common to southern Alberta. The results of these studies are shown in the following table —

TABLE SHOWING WATER HOLDING CAPACITY OF SOUTHERN ALBERTA SOILS

1	2	3	4	5	6	7	8	9	10
Type of soil	Depth	Hygroscopic coefficient	Wilting coefficient	Weight of a cubic foot of dry soil	Amount of water held when soil is saturated, i.e. all pore spaces filled with water	Maximum capillary capacity	Non-avaliable water	Maximum amount of available water held by soil with free drainage	Optimum available water content
	feet	%	%	lbs.	inches	inches	inches	inches	
Medium sand.	1	2.30	2.94	88	3.43	3.45	0.50	1.38	
	2	1.80	2.95	75	3.40	3.35	0.44	1.38	
	3	1.80	2.95	91	4.35	3.35	0.44	1.10	
	4	1.80	2.95	91	4.20	3.35	0.44	1.10	
	5	2.00	3.14	91	3.85	3.35	0.51	1.10	
	6	2.00	3.22	91	3.50	3.35	0.56	1.14	
Total					27.29	19.91	2.45	8.01	3 to 12 ins.
Sandy clay	1	4.10	6.03	89	5.65	3.94	1.43	3.91	
	2	3.00	5.14	10	4.50	3.32	0.89	3.40	
	3	4.10	6.03	82	4.43	3.54	1.47	3.47	
	4	4.10	6.03	82	4.24	3.54	1.47	3.47	
	5	4.10	6.03	82	4.07	3.54	1.47	3.47	
	6	4.20	6.82	82	3.89	4.45	1.33	4.30	
Total					26.78	23.37	6.35	15.72	3 to 10 ins.
Clay loam (30%)	1	6.30	9.85	74	8.97	4.27	1.40	3.47	
	2	6.32	9.30	77	8.81	4.15	1.35	3.77	
	3	5.82	8.87	80	8.50	4.15	1.35	3.44	
	4	7.30	10.72	88	8.32	4.40	1.71	3.39	
	5	7.78	11.40	88	8.45	4.47	1.38	3.59	
	6	7.89	11.20	89	8.67	4.43	1.92	3.71	
Total					39.42	23.67	9.59	18.89	4 to 14 ins.
Clay loam (50%)	1	6.50	10.15	70	8.75	4.04	1.70	3.44	
	2	4.82	7.22	78	8.60	4.35	1.46	3.15	
	3	4.88	7.15	86	8.26	4.15	1.19	3.14	
	4	4.82	7.82	88	8.03	4.39	1.33	3.06	
	5	5.33	7.82	100	5.19	4.43	1.50	3.99	
	6	5.20	7.85	102	4.32	4.32	1.59	3.89	
Total					35.15	25.20	8.66	17.41	3 to 12 ins.
Silt loam	1	3.40	3.10	78	4.70	4.60	0.53	3.46	
	2	4.40	7.20	85	4.50	4.50	1.17	3.48	
	3	4.10	6.40	98	4.50	4.60	0.98	3.33	
	4	3.90	5.20	88	4.50	4.60	0.90	3.42	
	5	3.50	5.40	88	4.50	4.60	0.90	3.42	
	6	3.50	5.10	88	4.20	4.60	0.82	3.97	
Total					34.70	25.00	5.17	22.43	3 to 17 ins.
Loam	1	3.40	5.10	75	5.78	3.70	0.73	3.96	
	2	3.40	5.10	80	4.18	3.70	0.87	3.83	
	3	3.40	5.10	80	4.54	3.70	0.87	3.83	
	4								
	5	Gravel							
Total					14.38	11.10	2.45	8.64	3 to 6 ins.

Column (1) and (2) give the type of soil and depth.

Column (3) gives the hygroscopic water content in per cent of the dry weight of soil. This is known as the hygroscopic coefficient.

Column (4) gives the wilting coefficient in per cent of the dry weight of soil. These figures represent the percentage of moisture the soil will contain when plants begin to wilt. When the percentage drops below the wilting point the capillary movement is so sluggish that the plants cannot obtain sufficient moisture to provide for normal growth.

Column (5) gives the weight in pounds of a cubic foot of soil in its natural condition. It ranges from 70 pounds for a clay loam soil containing considerable humus to 102 pounds for fine sands.

Column (6) gives the depth in inches that a soil will hold when saturated, that is when all the pore space of that soil is occupied by water and all air is excluded. This condition would only obtain where the soil was water-logged. The depths in this column indicate the pore space in the various soils.

Column (7) gives the maximum capillary capacity of the soil as determined by soil moisture tests made after heavy rains and irrigations. It represents the total amount of water a soil is capable of retaining against gravity under free drainage conditions.

Column (8) gives the non-available water content. It represents that amount of water which the soil will still contain when plants begin to wilt.

Column (9) gives the maximum amount of water available for plant use which a soil is capable of retaining against the pull of gravity under free drainage conditions. It is calculated by subtracting the figures of column 8 from the figures of column 7. It represents the amount of water which could be stored for plant use and varies from 8 inches in sand to 22 inches in silt loam for a six foot depth.

Column (10) gives the optimum available water content. The figures shown represent the available water contained when optimum conditions for plant growth prevail. It has been determined by experiments (Higard) that conditions are most favorable for plant growth when from 40 to 60 per cent of the pore space of the soil is filled with water, that is the pore space shown contained about half water and half air.

When more than 60 per cent of the pore space of the soil is occupied by water conditions become unfavorable for growth. The soil becomes cold, the activities of the bacteria which break down organic matter are restricted, plants have great difficulty in securing enough oxygen for their needs from the soil air and, in account of the high water content and consequent greater dilution of the soil solution, must transpire excessive amounts of water to secure the plant foods they require.

When less than 40 per cent of the pore space of the soil is occupied with water conditions become unfavorable for growth as the low water content makes it difficult for the plant to secure sufficient moisture for normal development.

It should be the aim of the irrigator to keep the moisture content of the soil within the optimum range. A study of the silt loam soil data is given in the preceding table shows that while this soil can hold contain 22.63 inches of water (column 9), this quantity would be too much; the soil would be too wet. Seventeen inches represent the maximum amount of available water this soil should contain and as 8 inches is the least amount it should contain, it follows that in a six foot depth the irrigator could store 8 inches of water for the use of the crop. The ideal practice then would be to bring the water content up to the highest optimum figure and then irrigate as often as necessary to keep the

moisture content within optimum range. For grains then, which feed to a depth of about four feet a five- or six-inch irrigation should be applied to this soil whenever the total water content to a depth of six feet drops to about 14 inches. (9 inches lower optimum range of available water plus 5.37 inches non-available water—14.37 inches total water content.)

A study of the data presented for the medium sand soil at Strathmore shows that while the silt loam soil has a maximum available water capacity of 22.63 inches for a six-foot depth, the sand only has a capacity of 8.01 inches, just a little better than one-third that of the loam. The figures given in column 10 for the sand show an optimum range of 8 to 13 inches. Therefore, under free drainage conditions this sand never could hold the optimum amount of water, it would never be too wet.

Again assuming that grain is grown on this soil which has a capacity of only 4.68 inches for the depth to which grain roots usually feed, irrigations of depths not exceeding four inches and should be applied with sufficient frequency to maintain the total available water content as near 8 inches as possible. The danger would not be in getting the sandy soil too wet, but in applying too much per irrigation. If a six inch irrigation were applied, at least 30 per cent of it would be lost to the grain by percolation.

With the same conditions would be reversed. Because of its ability to retain large quantities of water it would get too wet for an optimum crop before any appreciable loss would occur by percolation.

In the sand then, between its wilting point, where the total water content is only 2.85 inches in a six foot depth and its maximum available capillary capacity, where the water content to the same depth is 8.01 inches, there is storage for only 5.06 inches. This entire amount is held under sub-optimum conditions, for as explained previously, the optimum water content for the sand would range from 8 to 13 inches providing the sand could retain that amount.

The silt loam soil of the Brooks farm, between its wilting point, at which the water content to a six foot depth is 5.37 inches, and its optimum available capillary capacity, at which the water content is 17 inches, will hold to the above depth 11.63 inches of water.

Assuming that the two soils were dried out to their respective wilting points, an irrigator could store 5.06 inches of water in the Strathmore sand and 11.63 inches of water in the Brooks silt loam. In the former soil the entire amount stored would be below the optimum moisture range for that soil, while in the latter soil, only 3.63 inches of the amount of water stored would be below the optimum moisture range, and the remaining 8 inches would be within the optimum range.

Using the above data where the crops under irrigation are grain, feeding to a depth of approximately four feet the storage capacities would be  $\frac{1}{3}$  of the amount as given for a six-foot depth, as shown by the following table,—

	Below optimum range	Within optimum range	Total
	inches	inches	inches
For sand	3.38	8.46	11.84
For silt loam	3.43	14.20	17.63

From the foregoing data it will be obvious, that for grain crops irrigations of about four inches in depth on the light sandy soils and not exceeding six inches in depth in the silt loam soils, should be applied with sufficient frequency to maintain the moisture content within the range desired.

## SECTION 4

## FIELD OBSERVATIONS ON THE DEVELOPMENT OF THE SUGAR BEET ROOT SYSTEM

*In the Brooks and Raymond-Stirling Districts of Alberta, 1927*

## THE FUNCTION OF THE ROOT SYSTEM

The function of the root system is to gather from the soil the water, nitrogen and other food materials it contains and to deliver them to the above ground parts of the plant where they are converted into sugars, starches and other compounds for use in building up the cells of the plant as a whole and for its daily maintenance. As will be shown in the text to follow, the root will secure these necessary food materials with the least expenditure of energy possible.

To extend through the soil the root into even distantly located materials from the green leaves to convert into energy for its growth and as the function of the plant as a whole is to conserve these food materials for growth and reproduction the root system must not use any more energy in securing its food supply than is absolutely necessary.

The root will not develop into or towards a region containing no food or water but will expend its energy in growing towards and developing in the soil zone richest in the materials required. Jean and Weaver have concluded from their root development studies that in every case where roots are in contact with a soil layer or zone rich in available food materials they not only developed much more abundantly and branched more profusely than in zones of low soil fertility but this rich zone apparently retarded normal penetration into adjacent soil zones of lower fertility.

In 1927 the writer, in examining a sugar beet row near Raymond, Alberta, found a root behaviour in accordance with the conclusions of Jean and Weaver cited above. At a depth of 3½ feet the tap root penetrated a harder zone which had been filled in presumably by the animal life of earth worms, from near the surface containing considerably more organic matter and looser in colour than the surrounding silty soil. In the soil immediately above this burrow the tap root had developed single lateral roots  $\frac{1}{2}$  to 1½ inches in length and spread about  $\frac{1}{2}$  inch apart. After entering the rich zone at the bottom of the burrow the branching was very profuse. The root system seemed to have stopped at the presence of such an abundance of easily extracted food materials sending its branches into all parts of the burrow soil and branching again and again until the soil was a network of roots. The tap root did not appear to be the tap root.

*How Roots Secure Food and Water.* The absorption of water through the root hairs is the only means that a plant possesses of obtaining the various essential food materials which are derived from the soil for it is only when these necessary constituents are dissolved that they can find entrance to the plants.

Soon after the appearance of the primary root from a seed, secondary roots spring from it and from these new roots arise so that the soil becomes penetrated in all directions by fine rootlets near the ends of which numbers of root hairs are developed. As the rootlets pass the roots through the soil crevices of the soil, the root hairs grow into close contact with the small particles of soil and with the films of water surrounding the latter.

These tiny root hairs are really long, hollow tubes through the walls of which the food laden soil water is drawn by the force of osmotic pressure. They may be seen near the tips of growing rootlets with a magnifying glass. They grow, perform their work and die, as the root progresses through the soil. It is

only through these root hairs and the youngest part of the root in their immediate neighbourhood that absorption of water occurs. As the rootlet ages and the root hairs die off it becomes covered with a cork like layer. During the past season the writer observed that within one week after a heavy rain tiny hair-like rootlets had grown out into the cultivated furrow more at least six inches, or at the rate of about one inch in length per day. Later on, as the furrow again became dry, these roots died off only to be replaced by another similar system, after rains had again moistened the soil.

**What the Root Requires in Order to Grow.** To grow the root must first have energy or a motive power. This energy is secured from the sugars and starches that have been manufactured by the green leaves with sunlight and the carbon dioxide of the air and carried down where it is needed by the rootlet to produce new tissue and cells for growth. Having received this raw food material the rootlet must convert it into energy and to do this oxygen is required. This element is secured from the air contained in the tiny open spaces between the soil grains. The plant as a whole must have water, for without water the leaves could not grow and produce the food materials required by the root. Therefore the root must constantly have access to water.

A certain degree of warmth is needed in the soil at all times.

It has been shown that in order to grow the root needs food, air, water and warmth. Therefore any farming practice such as cultivation, irrigation, or timely cultural work that affects the supply of these necessary growth constituents will affect the growth of the root.

#### CONDITIONS AFFECTING THE SUPPLY OF GROWTH CONSTITUENTS

**The Food Supply.** The amount of available plant food in the soil largely determines the amount of crop produced per acre. It is dependent upon the amount of organic matter introduced into the soil from manuring or as a result of crop rotations and made available to the plant through microflora and other food-decomposing agencies. Sugar corn grown at the Illinois Irrigation Experiment Station yielded at the rate of twenty tons per acre when grown on soil that had been enriched by the growing of alfalfa or sweet clover and but ten tons per acre where grown on land of poor fertility or such as had been in grain crops for several years with no leguminous crop in the rotation.

Roots must have energy to grow. They obtain it from the leaves. The plant as a whole must have food to grow and produce leaves. Hence the food supply is one of the four great essentials for root development. *First, the raw food materials must be placed in the soil. Second moisture, air and warmth must be present for this food to become available to the plant.*

**The Air Supply.**—Air is essential to the conversion of the raw materials furnished the roots into energy for the growth of the root cells and for the use of the bacteria that convert the organic matter into available plant food. Roots will not grow normally when this air supply is restricted. Baking or puddling which takes air from the pore spaces of the soil, and a similar effect is caused by an excess of moisture. Conditions have been found most favourable for growth when the soil pore spaces contain about half air and half water. Heavy soils are more productive with an air content in the pore space of thirty-five to fifty per cent. Light soils with an air content of fifty to seventy per cent. The air supply of the soil must be maintained by keeping a proper amount of water in the soil and by thorough cultivation.

**The Moisture Supply.** Water is needed by the plant to maintain the turgidity of its growing cells. Whenever the water supply is insufficient to do this the cells become flaccid and the plant withers. Water dissolves the various

foods present in the plant and conveys them to the different organs of the plant needing nourishment. It brings into solution the plant foods present in the soil and conveys them through the roots to other parts of the plant where they are utilized. It is transported into the air through the stomata to keep the plant cool. It forms more than one-half the total weight of the plant, is the chief ingredient of the cell sap and is used to some extent as a food.

**The Optimum Water Content.** Experiments conducted at the Dominion Irrigation Experiment Station at Brooks, Alberta, showed that the most favourable moisture conditions for growth were attained when the pore space of the soil contained the following proportion of water: for a sandy soil 27 per cent, for a silt-sand soil 41 per cent, for a clay-sand soil 53 per cent.

When the moisture content was above the optimum per cent the excess of water not only lowered the soil temperature but cut down the air supply. When it was as great as less than the optimum per cent the moisture films were held so close to the soil grains and in film such force that the root hairs could not secure water in sufficient quantities to maintain healthy growth. When the soil is too wet the development of the plant as a whole is retarded because the roots cannot grow as they would for lack of air and warmth. When the soil is too dry root development is retarded because the plant as a whole cannot get enough water.

The amount of water obtained by the plant from any soil zone or layer is in direct relation to the development of root hairs absorbing moisture in that zone, as the movement of water by capillarity from one soil zone to replenish that abstracted from another zone is too slow to supply the needs of the rootlets. To secure an abundant supply the roots must grow to the water.

**The Amount of Water Used to Grow the Root Crop.** Irrigation investigations at Brooks in 1926 show that beets require approximately 20 acre inches of water annually to grow the crop when the soil moisture content is maintained throughout the growing season at the optimum per cent. Of this amount 50 to 70 per cent was required during the months of July and August. During the past season (1927) in the Magalloway district of Alberta a mean climate field showed a water use to grow the crop of 21 inches in May, 4.9 inches in June, 4.4 inches in July, 4.8 inches in August, 1.8 inches in September, and 0.7 inch in October, a total of 17.8 inches. The precipitation during this period was May 8.50 inches, June 2.10 inches, July 2.90 inches, August, 1.56 inches, September 3.30 inches, and October 0.58 inch up to the 19th of the month,—a total of 18.94 inches.

Having gained from the foregoing text a knowledge of the work of the root system of the sugar beet, how to do in the building up of the plant as a whole, of the sources of food supply and energy to the root, and of the conditions most favourable to root development, one can better understand and evaluate the following data on the development of the roots of sugar beets under varying conditions of soil, climate, soil fertility, and quality of soil water.

## SEASONAL DEVELOPMENT OF SUGAR BEET ROOT SYSTEMS: FIELD STUDIES 1927

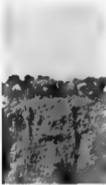
### INFLUENCE OF SOIL FERTILITY AND TEXTURE ON ROOT DEVELOPMENT

1. The development of the beet plant is dependent upon the available plant food in the soil.
2. The function of the root system is to obtain this food with the least expenditure of energy possible.

These two fundamental truths are emphasized in Plate I which shows the development of the beet plant as a whole on a light sandy soil of poor fertility (80c, top of plate) and on a silt soil of very high fertility (46c, bottom of plate).

Influence of Soil Fertility on Root Development  
Brooks, Alberta—Elevation, 2,450

46C.  
July 27 Length, 20", Diam. 1"-1½"



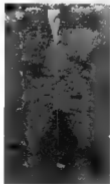
50C  
Sept. 27 Length, 50"-60" Diam. 2"-3"



46C.  
July 27 Length 20"-30", Diam. 1½"-2½"



50C.  
Sept. 27—Length, 50"-60", Diam. 2"-3"



Upper views show poor fertility—Sandy soil—Yield 9.7 tons per acre  
Lower views show excellent fertility—Silty soil—Yield 17.5 tons per acre

On July 27 the beets on the poor soil 90c had a root length of 20 inches and a diameter of beet top of 1 to 1½ inches while the beets on the rich soil, 46c had a root length of 32 to 38 inches and a top diameter of 1½ to 2½ inches. Both fields were planted May 1. Photographs were made of the beets on these same fields two months later and showing that the beets on the poor soil had attained a top diameter 2 to 3½ inches while those on the rich soil had top diameters of 3 to 5 inches. Plot 90c yielded when dug at the rate of 9.7 tons per acre. Plot 46c yielded at the rate of 17.5 tons per acre. There was a difference due to soil fertility of 7.8 tons per acre. The soil moisture content of each of these plots was maintained at the minimum by irrigation as required. Where the soil was rich the roots could obtain sufficient food for the normal growth of the entire beet plant, where the soil was poor they could not do so. The photographs taken on September 27 furnish an excellent illustration of the second truth as noted above. On plot 46c there was not only an abundant supply of food at moisture near the surface, due to the shallowness of the ploughed under, but there was also plenty of food and moisture lower down in the soil from the rotting alfalfa roots so that the roots did not have to travel very far or send out very many long or very heavy tendrils to secure their supplies. Conditions for this beet were just about right. Note its symmetry, the branches feeding in the furrow side and the few branches of moderate size necessary to secure supplies more down. Now note what has happened in the poor soil, d to 90c. In this case crop after crop of grain has been removed well giving a barrenness crop of a manuring of any kind to build up the soil's store of organic matter. The plant has sent several long slender roots down through the soil in search of food down to depths of 50 to 60 inches. Instead of one tap root going straight down as 46c this plant apparently took a side of the food supply's station after it had got down a foot or so and decided that the prospects of an root gathering sufficient food in such a poor soil were not very good. It therefore proceeded to subside and send down several roots and thus cover more territory. Due to lack of organic matter the furrow side on 90c dried out quickly and baked. This was unfavorable to root development in the furrow side. Summing up the information shown on Plate 1 we have: Where food is plentiful it is secured with less energy than where scarce. The energy thus conserved is fed into the beet.

## INFLUENCE OF SOIL AERATION ON ROOT DEVELOPMENT

### 1. Roots must have air and warmth to grow

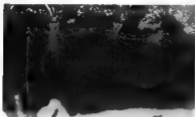
The three photographs on Plate 2 illustrate the development of sugar beet roots in a heavy wet clay soil near Hillspring, Alberta at an elevation of 2500 feet above sea level or 1400 feet above the experiment station at Brooks.

This field has been so wet all season from rainfall that the soil below a depth of three feet has been continuously saturated with water. The soil, for at least a foot above this water table contains so much water that the roots cannot secure enough air for normal growth. Although this field had an excellent stand of beets, was moderately high in fertility and well cared for it did not produce nearly so many tons of beets per acre as fields of like fertility under more favorable conditions of soil texture and drainage.

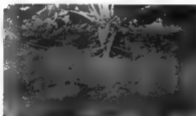
The high soil water content, slightly colder climate and heavy soil as compared to fields at Raymond and Brooks will account for the sub-normal root development and yield of this field.

On July 30 the beets had developed tap roots to a depth of around 20 inches with few and scanty branches towards the lower end of the tap root but with an abnormal development of long, heavy branches feeding close to the surface, especially in that part of the soil that had been stirred by the plough. On

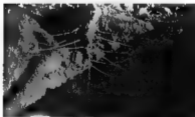
Beets in Wet Heavy Clay Soil at Elevation 3,440—Hill Spring, Alberta



Gibb—July 30—Length, 20", Diam. 2½"



Gibb—August 27 Length, 20", Diam. 3½"



Gibb—October 13—Length, 20" Diam. 4½"

August 27 the tap roots had attained a length of 24 inches with long (up to 36"), heavy branches in the surface 8 inches, a moderate number of branches 8 to 14 inches long in the zone of 8 to 16 inches depth and numerous, thread-like branches 1/2 an inch to 3/4 inches in length in the zone of 16 to 24 inches depth. On the same date plot 42c at Brooks, comparable in soil fertility and planted at the same time contained beets with tap roots 44 to 48 inches long. The soil of the Brooks plot had been better drained, contained a more favourable air supply and was therefore much warmer and more favourable for root growth than the Hillybrand plot.

On October 13 the tap roots had penetrated to a depth of 30 inches as compared with 55 inches on 42c at Brooks, but while the plant had made but little growth downwards it had made quite lengthy extensions and enlargements of the horizontal roots feeding in the surface 12 to 15 inches down. These latter roots extended from three to four feet in a nearly horizontal plane from the beet proper. Their greatest development was noted at the left side of the furrow where or along top of the plough side and in the plough stirred earth above this. The water table was one metre at a depth of three feet. Warmth and air were not available in the lower soil zones so the beet developed its root system in a more favourable environment nearer the surface.

#### INFLUENCE OF ALKALI SOIL ON ROOT DEVELOPMENT

Dr J. D. Newton of the University of Alberta found that: "The rate of plant root respiration as related to transpiration is increased when the salt concentration of the culture solution is increased, and that: 'This indicates that as the concentration of the culture solution is increased the plant roots must expend more energy in absorbing a given volume of solution.' That is, the plant would need to use more food to secure the amount of water it needed where growing in an alkali soil than where growing in a non-alkaline soil."

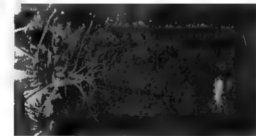
Hilbert (13) found that beets growing in a moderately strong alkali soil became dwarfed.

Hilbert (14) found when strong solutions of certain salts came in contact with the root hairs the latter refused to take up any water, and that while a true salt test upon the plant as a first test, positive other salts in the soil solution would cause the solution on the outside of the root hairs to have a greater attraction for water than the solution on the inside of the root hair and therefore under certain conditions the root hair would be unable to obtain any water from the soil but might actually lose the water it contained back into the soil.

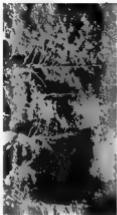
Cannon (15) found that "the root oxygen in the soil is a limiting factor of root growth at any temperature."

Plate 3 shows the root development of beets growing on a wet alkaline soil near the Raymond Alberta sugar factory. On July 21 these beets had a tap root length of but 12 to 14 inches as compared to a length of 20 inches attained by the beets on the Peterson field, a well drained, alkali-free soil located some few miles west. Compare with left photo on Plate 4. These beets have already shown an abnormal root development. The lateral roots were much more numerous and heavier than those of the beets on the Peterson field. Comparing again the development of the beets on the factory farm on August 23 with those of the Peterson farm on the same date some striking differences in growth are apparent. The Peterson beets have developed a single symmetrical tap root to a depth of 34 inches with a profusion of horizontal branches extending from a few inches to two feet in a horizontal plane on a sides of the tap root indicating that food, moisture and air conditions were about normal throughout the entire depth occupied by the root system. The factory beets have adopted an entirely different method of feeding and instead of a single tap root system have

Beets in Wet No. 1. High P. A. kal no—Raymond, Alberta.—Elevation, 5,100



Factory Aug 23 Length 27", Diam. 3 1/2"



Factory—July 24 Length 13" 14", Diam. 1 1/2 2 1/2"



Factory Sept 23 Length 24", Dia n. 3 1/2"

shown a tendency to feed nearer the surface and have developed several slender roots spreading fan-shaped from the bottom of the beet and extending to the depth of 27 inches at which depth the soil was found to be saturated with water. On September 23 the factory beets had penetrated to a depth of 28 inches but one inch deeper than on August 23 and had seemingly ceased all effort to obtain food supplies in any way, none except that from the surface to a depth of about 13 inches. In this case the main rootlets had grown to lengths of from 30 to 90 inches extending in a nearly horizontal plane from the beet and seldom extending any secondary branches to a greater depth than 15 inches. These main roots had reached a thickness of from 1 inch to 1½ inches where they joined the beet. The beet was malnourished and when tested showed a sugar content of from 2 to 3 per cent below the average for the district a much lower per cent of purity and contained so much fibre that considerable difficulty was experienced in slicing them in the factory. Root (A) shown in the plate was traced from a beet in the next row to the left of the beet shown in the photo and extended to a length of nearly eight feet.

The actual weight of the root system of this beet would be greater than that of the Peterson field beet as shown on September 23. The factory beet has expended so much energy in the development of its root system in an endeavour to secure food under very unfavourable conditions that an insufficient amount of food has been left to be built into the beet proper.

The soil below a depth of 13 inches was very wet with water table at three to four feet. The surface soil ranged from wet after rains to quite dry between rains and when dry showed white incrustation of salts on the surface.

The development of the root system of this beet seems consistent with the facts that have been presented relative to the soil conditions affecting the food supply of the plant. The lower soil zone was wet and therefore contained very little oxygen and roots cannot grow without oxygen; the soil water contained especially in the lower soil zones a large amount of alkali probably of so high a concentration that the roots could obtain no water whatever from it. Therefore very little root development occurred below a depth of 13 inches. In the surface 13 inches the alkali content of the soil water was much less and the soil warmer and better aerated, the plant could secure some food but at a relatively high cost for energy consumed in the food gathering process.

#### PLATE 4—NORMAL DEVELOPMENT IN A CLAY-LOAM SOIL, WELLING, ALBERTA, 1927

The photographs presented on Plate 4 show the seasonal growth of the root system of beets in a well drained clay loam soil at the Peterson farm near Welling, Alberta. The growth of these beets may be considered as normal and representative of the development of beets in soil of similar texture, fertility and moisture content in the Magrath-Sterling district.

July 23—Length of tap root 20 inches. Diameter of beet at crown 1½ inches. Several fine roots up to 12 inches long feeding in surface 4 inches of soil.

August 23—Length of tap root 34 inches. Diameter of beet at crown 3½ inches.

September 23—Length of tap root 50 inches. Diameter of beet at crown 4 inches. Well developed root system to a depth of 50 inches. From three to five branches take off from the tap root at about half depth spread out to cover a soil block of 18 to 25 inches in diameter and grow nearly straight down. Above this division point and between it and the bottom of the beet are numerous roots extending in a nearly horizontal plane to lengths of from 6 to 18 inches. The furrow slice was filled with thread like roots, apparently more than one development of them as they were observed to extend from the sides

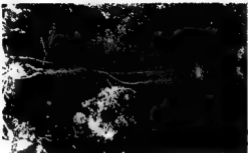
Herbs on Wetland near Clay Lane S. of Lake Fort St. J.



July 21 1942 11:30 A.M.



July 21 1942 11:30 A.M.



July 21 1942 11:30 A.M.

of the beet out into the furrow since, in some instances at the rate of one inch in length per day especially after a heavy rain, and then to die off during a period of drought, only to be succeeded by another development as moisture and the products of nitrification again became available.

# PLATE 5.—NORMAL ROOT DEVELOPMENT ON A SANDY LOAM SOIL, STERLING, ALBERTA

The photographs presented on Plate 5 show the normal development of the root system of beets grown in a sandy-loam soil at the Hogansen farm near Sterling, Alberta.

This soil was well drained in the early part of the season, but due to heavy rainfall and the presence of a gumbo stratum at  $4\frac{1}{2}$  feet depth had a tendency to become too wet in the third and fourth feet towards the end of the season. Some standing water varying in depth from 2 to 4 inches, was noted immediately above the gumbo stratum in the latter part of the season. This limited the downward growth of the roots on this field. In a field of similar soil texture some distance away, and well drained, the tap roots had reached a depth of 88 inches on October 2.

July 28 Length of tap root 20 inches, diameter of beet at crown,  $1\frac{1}{2}$  inches.

August 24 Length of tap root 42 inches diameter of beet at crown,  $3\frac{1}{2}$  inches.

September 30 Length of tap root 46 inches, diameter of beet at crown  $4\frac{1}{2}$  inches.

The general root development of this field is quite similar to that depicted on Plate 4. There is, however, considerable difference in the rate of root growth in the two soils.

## DEPTH OF TAP ROOT PENETRATION

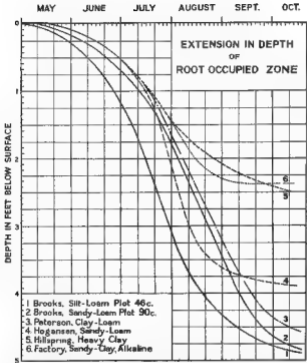
	July 28-28		Aug. 23-24	Sept. 23-29
Plate 4. Peterson. Growth during period.	20 ins.	14 ins.	34 ins.	50 ins.
Plate 5. Hogansen. Growth during period.	20 ins.	22 ins.	42 ins.	46 ins.

Between the July and August observations, in approximately one month, the tap roots on the light sandy loam soil, had grown 22 inches as compared with a growth of but 14 inches on the clay-loam soil.

The next period, one month, between August 23 and September 23, showed the roots in the sandy-loam soil to have grown but 4 inches as compared with 16 inches in the clay-loam soil. The roots in the Hogansen field had reached the nearly saturated soil above the water table at the four foot depth and had stopped downward growth, while those on the Peterson field, being in well aerated soil, continued to grow.

## EXTENSION IN DEPTH OF ROOT-OCCUPIED ZONE

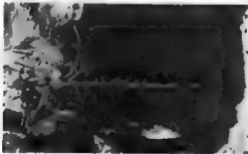
Graph shows the depth of tap root penetration on six fields of beets as determined by investigations during the growing season of 1927. Curves 1 and 2 represent the growth of the tap roots on plot 46c fertile silt-loam, and on plot 90c infertile sandy-loam at Brooks, Alberta. The fertility of plot 46c was higher than that of any other field studied during the season. It shows a greater



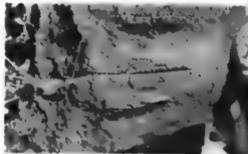
depth of root penetration on any date during the growing season than any of the other fields. The roots here have grown rapidly until they approached the zone of high water content in the fifth foot, when the rate of penetration decreased. Plot 90c, on less fertile but lighter soil, made less rapid growth up to August 1 than 46c, but a more rapid growth during the remainder of the season, due to lighter soil and better aeration in lower soil zones.

The beets of fields 3, 4, 5 and 6 had reached approximately the same depth at mid-July. After this date the beets on fields 3 and 4 being in warmer, dryer soil, made better progress than the beets on the wet, heavy soils of fields 5 and 6. The beet roots on field 4 made rapid extension until they approached the water table. A decided break in this curve is apparent at about 42 inches depth. Similarly the beets on field 6 made rapid growth until they approached the water table. At a depth of 26 inches a break in the curve is noted about August 20, after which very little extension in depth is noted.

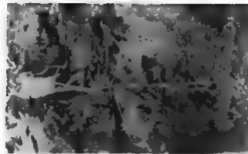
Birds on Sandy Lagoon Bird with Grackle Larvae and Waders at 41 Ft. Depth



Mayaguez July 28 Length 26" Depth 41"



Mayaguez Aug 1 Length 27" Depth 41"



Mayaguez—Sept. 26—Length, 44", Depth, 44"

For all fields, the most rapid growth was made during the months of July and August, when all soil conditions for growth were most favourable,—warmth, aeration and moisture.

### DISCUSSION OF YIELDS

The foregoing study was devoted principally to the development of the beet plants as individuals under certain soil environments and not to the yield of the field as a whole. The plants studied were typical of the average plants of a field. The surface moisture in the spring and consequently the stand resulting therefrom varied considerably over any field. After the heavy spring rains the higher portions of a field dried out on the surface and formed a crust that prevented a good stand being obtained. The surface of the lower lying portions of the same field remained wet and formed a crust thus permitting of a perfect stand of beets. Due to this variation in stand and to the unfavorable weather at the wet times which prevented a considerable storage being laid before being covered with snow, the yields of the field as a whole are not as consistent with the environment of the plants studied as they would be under more favourable weather conditions.

Plot	Index of soil fertility	Optimum moisture	Stand	Yield per acre in tons	Water consumed	Principal factors limiting yield
Brooks 46c	High	Optimum	Fair and dense	20.0	17.1	
1. Brooks 46c	High	Optimum	Base wet	17.5	19.0	Fertility
2. Peterson	Medium	Optimum	Good	13.0	21.2	Stand and soil fertility
3. Eakery	High	Too wet	Good	10.0	16.4	Wet alkali soil
7. Brooks 46c	Low	Optimum	Good	9.7	13.8	Stand and soil fertility
8. Gibbs	Off-high	Too wet	Good	9.0		Cold, wet alkali
4. Haganen	Low	Optimum	Poor	8.0	17.2	Stand and soil fertility

Brooks Plot 46c with a yield of 20 tons per acre will be taken as a basis of comparison as this plot apparently had no yield limiting factors except that the stand was 80 per cent instead of 100 per cent. Plot 46c at Brooks had as good a stand as 68c and optimum moisture conditions during growth. It yielded 2½ tons per acre less than 68c due to a slight depletion of fertility. The yield of the Peterson plot was limited principally by soil fertility and somewhat by stand. The yield of the Eakery plot was limited principally by high water table and alkali. Brooks plot 90c gave a low yield due principally to low soil fertility. The Gibbs plot had about the same fertility as plot 46c at Brooks but not quite as good stand. Its lower yield as compared with that of 46c was due to a slightly cooler climate due to being nearer the mountains and at a higher elevation than Brooks 46c and to having a heavy clay soil containing too much water. The yield of the Haganen plot was limited by low fertility and by poor stand. Most of the fields cited above had optimum moisture conditions throughout the season. Two fields were too wet due to high water table. The principal factors limiting yield were soil fertility and stand.

### RELATION OF ROOT DEVELOPMENT TO DEPTH REQUIRED FOR IRRIGATION

Sandy soils will retain (that is hold water up in the soil against the pull of gravity) from ½ to 1 acre-inch of water per foot in depth of soil depending on the soil texture, the coarse sands holding the smaller amount.

Loam soils will hold from 1½ to 2½ acre-inches of water per foot in depth of soil. Fine silt or silt-loam soils will hold from 2½ to 3½ acre-inches and heavy clays from 3 to 5 acre inches per foot in depth of soil.

Under good irrigation practice it is unprofitable to allow the plant to completely exhaust the available moisture supply of the root zone before applying the next irrigation so that under average conditions we find that the irrigated soil retains from  $\frac{1}{2}$  to  $1\frac{1}{2}$  acre-inches of water per foot in depth of soil from each irrigation.

Considering these data in connection with the depth of root-occupied soil zone we have

Age of Beets	Depth of root-occupied zone in feet	Average amount of water that can be retained in the root-occupied zone from an irrigation, in inches.		
		Fine	Loam	Silt
1 month	0-8	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
2 months	1-0	$\frac{1}{2}$	1	$1\frac{1}{2}$
3 months	2-0	$1\frac{1}{2}$	3	4
4 months	4-0	3	4	8
5 months	5-0	3 $\frac{1}{2}$	5	7

*For sandy soils* a 3- or 4-inch irrigation would always be more than enough to apply. A 2-inch irrigation would be much more economical in the early stages of growth.

*For loam soils* the correct depth per irrigation will vary from a 3-inch irrigation in the early part of the season to a 5-inch irrigation in August and September.

*For Silt soils.* The silt and silt-loam soil will retain up to a 7-inch irrigation late in the season but it will be found much more profitable to apply this amount in two  $3\frac{1}{2}$ -inch irrigations than in one application of 7 inches depth.

Only light irrigation should be applied to sugar beets in the early part of the season, especially on lands underlain with an impervious stratum or poorly drained.

#### CONCLUSIONS

**1 Development of Plant dependent upon Supply of Food, Moisture, Air and Warmth.**—The development of the plant as a whole depends upon the development of the root system. The development of the root system is dependent upon the supply of air, plant food, moisture and warmth. The supply of these constituents in the soil may be regulated by crop rotation, manuring, irrigation and drainage.

**2 Correct Moisture Content must be Maintained.**—The soil, especially the surface zone containing the bulk of the plant food, must be maintained at the proper moisture content throughout the growing season so that roots can develop therein and extract food.

**3 Light Irrigations Should be Applied to Supplement Rainfall.**—When the rainfall is not sufficient to maintain the soil at the proper moisture content the deficiency should be supplied by no more than that required to raise the moisture content of the root occupied zone up to the optimum moisture content. This will necessitate the application of light irrigations, especially in the early part of the growing season. Better results will be attained by the application of a given amount of water in frequent light rather than few heavy irrigations. The reason is obvious—because so large a proportion of the water applied in a heavy irrigation is lost to the plant by percolation below the root occupied zone. This percolation removes plant foods. With light irrigations applied frequently, the fertile soil zone near the surface is more nearly maintained at the optimum moisture content.

### CLASSIFIED LIST OF PUBLICATIONS

**WATER POWER**

The Reports pertaining to Water Power published by the Dominion Water Power and Reclamation Service in the course of the annual Reports have been called Water Resource Papers, and have been numbered 1, 2, etc.

Annual Reports for 1982 are included with the Annual Report of the Department of the Interior and can be ordered from the directors of the department.

Annual Reports for the fiscal years ending March 31 from 1963 to 1969 are available from the National Library of Medicine, Bethesda, Maryland 20894. For 1962, the first report concerning the poisoning of the White River and Redaktionen, a volume of the series.

JOURNAL OF SPECIAL AND CLINICAL EDUCATION

[illegible]

Water Resources Paper No. 2. Reported on Forest and Rangeland Investigations, Washington, D. C., U. S. Forest Service, 1942. 134 pp. 10¢. (Forest Service, Washington, D. C.)

**Water Resources Paper No. 2.** The subject Report on the Pasqua Reservoir Project by T. H. Dyer, is being used as a teaching material source. It was a program report and is being used to help students determine the propriety of lowering the level of Federal aid to a project of this type. It was used in the teaching units on questions to the students on the subject of Federal aid to water projects. Published 1941 by the United States Government Printing Office.

**Water Resources Paper No. 4.** Report on cost-effective means of power for pumping water from the South Saskatchewan River Basin. Prepared by H. F. M. Jones. It describes the means of power for pumping water from the South Saskatchewan river to the supply channel and main on the central portion of south Saskatchewan. Published 1964. Out of print.

Water Resources Paper No. 7. Report on a Manitoba Water Project by D. I. McLean, D. H. Fox, and J. T. Jones. Published by Manitoba Public Document Commission. 4 pages and 1 figure. Includes a table and an index. The work of the general commission is published in the *Journal of the Manitoba Water Resources Commission*. Published 1984. Reprinted by No. 86.

Water Resources Paper No. 14. *Hydraulic Guide for Compilation of Water Power Reports of the Division of Water Power Research* prepared by the guidance of Field Engineering of the Division of Water Power Research by J. T. Johnson, chief hydraulic engineer. Published 1935. Limited edition.

Water Resources Paper No. 11. Second Report on the Pampas Reclamation Project by T. H. Danks, in charge of Reclamation Survey. This is a preliminary Report based on further knowledge as accumulated under Water Resources Paper No. 1. Published 1915. Out of print.

**Water Resources Paper No. 12** Report on Rural Water Potency in Western Canada and  
 design is suggested. Part I is the Foreword by A. M. Steele. Part II is a brief description  
 of the rural water supply situation in the various provinces. Part III gives an analysis of  
 the various water supply systems. Table 1913, 1914, 1915, 1916, 1917, 1918, 1919, 1920, 1921, 1922, 1923, 1924, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1936, 1937, 1938, 1939, 1940, 1941, 1942, 1943, 1944, 1945, 1946, 1947, 1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955, 1956, 1957, 1958, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 258

Water Resources Paper No. 11. Report on the Composite Studies. Hydro-Electric Development. A complete description of the project and of the details of construction, with plans, diagrams and illustrations by G. L. Colquhoun, Chief Engineer of the British Columbia Electric Railway Company Limited. Published 1913.

## CLASSIFIED LIST OF PUBLICATIONS—Continued

- Water Resources Paper No. 16.**—**Water Powers of Canada.** A series of five pamphlets in one volume covering the water-power situation in Canada, prepared for distribution at the Panama Pacific Exposition, San Francisco, 1915 by G. R. G. Conway consulting engineer Toronto, Percival H. Mitchell consulting engineer Toronto, H. G. Acres, hydraulic engineer, Hydro-Electric Power Commission, Ontario, F. T. Kneib, assistant chief engineer, Shawinigan Water and Power Co., Montreal, K. H. Smith engineer, Nova Scotia Water Power Commission, Halifax, N.S. Published 1916. Out of print.
- Water Resources Paper No. 17.** **Canadian Hydraulic Power Development and Electric Power in Canadian Industry** by Charles H. Mitchell consulting engineer to Dominion Water Power Branch. Part I deals with progress of utilization, features in design, construction and operation especially applicable to Canada. Description of certain typical Canadian water-power developments. Part II outlines the past growth and future of electrical power in Canadian industry. Published 1915. Out of print.
- Water Resources Paper No. 20.** **Report on the Interests Dependent on Winnipeg River Power with Special Reference to the Capital Invested and the Labour Empowered** by H. E. M. Knight. A detailed study of the industrial growth and future power requirements of the district tributary to the Winnipeg River power area. Published 1917. Out of print.
- Water Resources Paper No. 27.** **Directory of Central Electric Stations in Canada to January 1 1919** compiled by J. T. Johnston, assistant director [See also Water Power Branch Composites an analysis of the central electric station statistics and a directory of the stations. Published 1919. Out of print.
- Water Resources Paper No. 32.** **Water Resources Index Inventory** by J. T. Johnston. Describing use of the Index Inventory sheets for recording and relating the water resources data of the Dominion. Published 1929. Out of print.
- Water Resources Paper No. 33.** **Directory of Central Electric Stations in Canada to November 1 1922** Comprises an analysis of the central electric station statistics and directory of the stations. Published 1923. Out of print.
- Water Resources Paper No. 35.** **Directory of Central Electric Stations in Canada, to May 1 1925** Comprises an analysis of Central Electric Station statistics and directory of the stations. Published 1929. Price 50 cents.
- Water Resources Paper No. 36.** **Water Powers of Manitoba.** Administration, developed power and available undeveloped power by C. H. Atwood, district chief engineer. Published 1926.
- Water Resources Paper No. 40.** **Water Powers of Canada.** A general review of the water-power resources of Canada as to investigation, administration, developed power, use of power in industry and available undeveloped power by J. T. Johnston, Director of Water Power and Reclamation. Published 1927.

## SURFACE WATER SUPPLY REPORTS

## ATLANTIC DRAINAGE SOUTH OF ST. LAWRENCE RIVER INCLUDING NOVA SCOTIA, NEW BRUNSWICK, PRINCE EDWARD ISLAND, AND SOUTHEASTERN QUEBEC

- Water Resources Papers Nos. 29, 37, 43, 52 and 63.**—**Surface Water Supply of Canada.** Report on hydrometric surveys covering the Atlantic drainage south of the St. Lawrence river including Nova Scotia, New Brunswick and Prince Edward Island and southeastern Quebec for the climatic years ending September 30 1919 to 1926, by K. H. Smith and K. G. Chabolin, district chief engineers.

## ST. LAWRENCE AND SOUTHERN HUDSON BAY DRAINAGE IN QUEBEC

- Water Resources Papers Nos. 41, 48 and 58.** **Surface water supply of Canada.** Reports on hydrometric surveys covering the St. Lawrence and southern Hudson Bay drainage in Quebec for the climatic years ending September 30 1923 to 1927 by Leo G. Deane, district chief engineer.

## ST. LAWRENCE AND SOUTHERN HUDSON BAY DRAINAGE IN ONTARIO

- Water Resources Papers Nos. 38, 39, 42, 43, 47 and 55.** **Surface water supply of Canada.** Reports on hydrometric surveys covering the St. Lawrence and southern Hudson Bay drainage in Ontario for the climatic years ending September 30, 1920 to 1927, by district chief engineers.

## CLASSIFIED LIST OF PUBLICATIONS—Continued

## ARCTIC AND WESTERN HUDSON BAY DRAINAGE (AND MISSISSIPPI DRAINAGE IN CANADA) IN ALBERTA, SASKATCHEWAN, MANITOBA, EXTREME WESTERN ONTARIO, AND NORTHWEST TERRITORIES

**Water Resources Papers Nos. 4, 19, 22, 24 and 26.**—Surface water supply of Canada. Reports on hydrometric surveys in Manitoba, from January 1, 1912, to September 30, 1919 by M. C. Mondry and C. H. Altwood, district chief engineers. No. 4 contains a gazetteer of lakes and streams in Manitoba.

**Water Supply Bulletins Nos. 1 to 11.**—Surface water supply of Canada. Reports on hydrometric surveys in Alberta and Saskatchewan from 1908 to September 30, 1919, by P. M. Sweder and A. L. Ford, chief hydrometric engineers, Reclamation Service.

**Water Resources Papers Nos. 31, 36, 40, 44, 46, 50, 54, 57 and 62.**—Surface water supply of Canada. Reports on hydrometric surveys covering the Arctic and western Hudson Bay drainage (and Mississippi drainage in Canada) in Alberta, Saskatchewan, Manitoba, extreme western Ontario and Northwest Territories, for the climatic years ending September 30, 1920 to 1928, by C. H. Altwood and A. L. Ford, district chief engineers. Previous to 1919-1920 the surveys in Alberta and Saskatchewan were carried on and the results published by the Reclamation Service, Department of the Interior.

## PACIFIC DRAINAGE IN BRITISH COLUMBIA AND THE YUKON TERRITORY

**Water Resources Papers Nos. 1, 8, 14, 18, 21, 23, 25, 30, 35, 39, 43 47, 51, 53, 59 and 61.**—Surface water supply of Canada. Reports on hydrometric surveys covering the Pacific drainage in British Columbia and the Yukon Territory from May, 1911, to September 30, 1928. No. 1 is by P. A. Carson, chief engineer, the others by R. G. Swan and C. E. Webb, district chief engineers. No. 1 contains an outline of the history of the Railway Belt with special reference to its administrative legal and physical problems in regard to water, and a gazetteer of the lakes and streams in British Columbia.

## MAP

**Water Powers of the Dominion of Canada prepared in connection with the first World Power Conference, London, Eng., 1924.**

## RECLAMATION

**Drainage Regulations.**

**Irrigation Regulations.**

**Annual Irrigation Reports—1894-1911.** Out of print.

**Annual Irrigation Reports—Calendar Years, 1912 to 1915.** Out of print.

**Irrigation Surveys and Inspection Reports—Fiscal Years, 1915-16, 1916-17, 1917-18, 1918-19.** Out of print.

**Annual Report of the Reclamation Service—1919-20, 1920-21, 1921-22, 1922-23.**

**Annual Report of the Dominion Water Power and Reclamation Service—1923-24, 1924-25, 1925-26, 1926-27, 1927-28.**

**Annual Stream Measurement Reports of Alberta and Saskatchewan—Water Supply Bulletin Nos. 1-11, 1909-1919.** Out of print. Continued in Water Resources Papers Nos. 31, 36, 40, etc.

**Western Canada Irrigation Association Reports—1st to 11th Convention. (1907 to 1917).** Out of print.

**International Irrigation Congress Report—1914.**

**Bulletin No. 1—Irrigation in Alberta and Saskatchewan.**

(Consisting of a Synopsis of the Irrigation Act and its Administration.)

**Bulletin No. 2—Alfalfa Culture.** Out of print.

**Bulletin No. 3—Climatic and Soil Conditions, C.P.R. Irrigation Block.**

**Bulletin No. 4—Duty of Water Experiments and Farm Demonstration Work.** Out of print.

**Bulletin No. 5—Farm Water Supply.**

**Bulletin No. 6—Irrigation Practice and Water Requirements for Crops in Alberta.** Out of print. See Bulletin No. 7.

**Bulletin No. 7—Irrigation Practice and Water Requirements for Crops in Alberta (Revised Edition of Bulletin No. 6).**



S 613 567 1930

SNELSON W H

IRRIGATION PRACTICE AND WATER  
REQUIREMENTS FOR CROPS IN  
39821437 SCI



-000017251612-

S 613 567 1930

Snelson, W. H.

Irrigation practice and water  
requirements for crops in  
39821437 SCI

B34858

Water Resources Papers, and Irrigation and Drainage Reports,  
as listed at the end of this report are issued gratis, with  
the exception of Water Resources Paper No. 55, for  
which a charge of 50 cents is made. These can  
be had on application to the Director of  
Dominion Water Power and Reclamation  
Service, Department of the Interior,  
Ottawa.